NASA/CR—1999-209159

The Component Packaging Problem— A Vehicle for the Development of Multidisciplinary Design and Analysis Methodologies

Georges Fadel, Michael Bridgwood, Richard Figliola, Joel Greenstein,
Michael Kostreva, Ronald Nowaczyk, and D. Steve Stevenson
Clemson University, Clemson, South Carolina

Prepared under Grants NGT10008 and NAG3–2046

National Aeronautics and
Space Administration

Glenn Research Center

June 1999

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076
Price Code: A06

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100
Price Code: A06

Table of Contents

Executive summary 1
Goals: 1
Faculty Team selection 2
Mechanics 2
Accomplishments 2
Shortcomings 3
Approach 3
Undergraduate program 3
Assessment 4
Team Success as it Relates to Team Member Personalities 5
Team dynamics 5
Personality types 6
The Problem 6
Proposal problem. 6
The products 6
Shared Expertise - Background & Problem 7
Approach & Findings 7
Laboratory class development in Multidisciplinary Analysis 7
Graduate Program 8
Research issues 8
Optimizing the Product Development Process through Computer-Supported Internal Collaboration 8
Background 8
The Need for Internal Collaboration 8
Objectives 8
Work Accomplished 9
Potential Payoffs 9
Development of Design Guidelines for Computer-Based Tools to Support Multidisciplinary Design 9
Background 10
Objectives 10
Approach 10
GroupWare Platform 11
Multidisciplinary Coordination 11
Decomposition of Design Data 12
Virtual Reality CAD/CAE Prototyping System 12
Improvement to Optimization Algorithms 14
Incorporation of electronic system design in the MDO Environment 15
Introduction 15
Electromagnetic Compatibility 15
Thermal Interactions 15
Research Plan 16
Optimization – Rubber Band packing 16
Optimization – Heat Exchanger multi-objective design 16
Multidimensional visualization 17
Configuration Design optimization Method 18
Problem selection 18
Achievements 21
Discussion of the Results and Criticism 24
Implications for Future Research 25
Summary 26
Shortcomings and roadblocks 26
Roadblocks to the implementation 27
Research Roadblocks 27
Future work 28
Conclusions 31

List of Undergraduate participants 32
List of Graduate Participants 32
Papers, reports and Presentations 33
Theses 39
Coupled Multidisciplinary Optimization 39
Perceptual & Oculomotor Implications of Interpupillary Distance Settings on a Head-Mounted Virtual Display. 39
A Methodology for Decomposition in Design 40
Norm-Relaxed Method of Feasible Directions 40
Using Functions and Metrics at the Conceptual Stage of Mechanical Design 41
Virtual Prototyping, a Step Before Physical Prototyping 41
Thermal Optimization of the Environmental Control System on an Advanced Aircraft with an emphasis on System Efficiency and Design Methodology 43
Three-Dimensional Pipe Routing using Genetic Algorithms and Tessellated Objects 43
Constraint Reordering for Multi-Objective Configuration Design 44
Aspects of Air Flow Control in a very low Velocity Wind Tunnel 44
Minimax Optimal Control of Steady State Systems 45
The Use of Computer Supported Cooperative Work Applications in Student Engineering Design Teams: Matching Tools to Tasks 46
Bi-Objective Optimization of an Automotive Heat Exchanger Using Computational Fluid Dynamics 47
Appendices 50
Industrial Feedback 50
Comments on Clemson Discussion Topics from Paul Cole, Lockheed Georgia 50
Response from Steve Lancaster, Martin Marietta 52
Letter 1. Advertisement letter 54
Letter 2. Invitation to Apply 55
Letter 3. Welcome to the AMDAF 56
Web site CIRCULAR 57
MDA Application 61
MDA Curriculum 62
Assessment letter from undergraduate student 64
1st year presentation
2nd year presentation
3rd year presentation

Executive summary

In response to a BAA issued by NASA Headquarters to investigate Multi-disciplinary Analysis and Design issues, a team of faculty from Clemson University was formed and developed a proposal to address this type of problem. The team, which consisted of faculty from Mechanical Engineering, Electrical Engineering, Industrial Engineering (from the former college of Engineering), Mathematical Sciences, and Computer Science (from the former college of Science) and Psychology (from the former college of Liberal Arts) was small enough, yet diverse enough to effectively tackle the problem. The Packaging problem (placing multiple components under the hood of a car, placing satellite components in a satellite, laying out the avionics bay of an airplane) was selected by the team for its applicability to diverse fields. It brought together all the disciplines represented in the team, and required a focused effort to develop coordination techniques, optimization and approximation approaches, teaming issues, and visualization paradigms among others. It was also of interest to our industrial partners, The Lockheed Corporation and Martin Marietta Corporation. Ironically, within one year of the start of the project, Clemson University underwent a major restructuring in which a number of colleges and departments were merged. Today, most of the participating faculty belongs to the College of Engineering and Science. Simultaneously, Lockheed and Martin Marietta merged into the Lockheed Martin Corporation.

Clemson University was one of five institutions selected to work on the problem. This report summarizes our efforts over the past few years, highlighting our accomplishments, yet showing that there is still far to go to overcome institutional, procedural, and personal hurdles.

From the onset, the team decided to follow a two-prong approach: one, to bring multidisciplinary issues to the undergraduate education and experience; and two, to build up research issues to support the coalescing of applications and science to deal with coupled complex problems at the graduate level. To this effect, the following goals were agreed upon.

Goals:

At the *undergraduate level:* develop and offer a certificate program that broadens the exposure of selected students. Such a program should encompass both course work and practical applications aiming at producing a better understanding of multidisciplinary issues. In particular, the program should address teaming issues and an appreciation and understanding of another discipline, and better prepare the students to work in a multidisciplinary environment.

At the *graduate level*, select research topics that target the development of theories and procedures to facilitate work in a multidisciplinary environment. The research topics must address such issues as collaborative environments, visualization or teaming which support the communication aspect of multidisciplinary problems. They must also target the development of optimization, approximation and simulation tools that provide the mechanistic underpinnings of the multidisciplinary design theories.

To support the educational experience, industrial buy-in in terms of financial support, summer jobs, visits and problem identification must provide credence and validation to the work undertaken.

Finally, the research has to lead to concrete solutions to relevant problems that could be presented initially in conference proceedings, and then eventually in appropriate journals. This would provide the necessary validation to the proposed approaches by subjecting the work to peer review and dissemination.

Faculty Team selection

The Faculty team had to provide adequate disciplinary expertise, and learn to deal with the multidisciplinary issues. As mentioned earlier, the initial team included two professors from the Mechanical Engineering department, Dr. Georges Fadel, the project leader, with experience in system design and optimization, and Dr. Richard Figliola, currently department chair and a specialist in thermal and fluid systems, aerodynamics and instrumentation. The Electrical and Computer Engineering faculty member, Dr. Michael Bridgwood, brought expertise in instrumentation. The Industrial engineering team member, Dr. Joel Greenstein researched human factor issues and collaborative design systems. To support the optimization research, Dr. Michael Kostreva, from the Mathematical Sciences department, provided rigor and scientific formalism to the approaches developed. Dr. D. Steve Stevenson from the Computer Science Department supported the work in visualization, and the computational issues in collaborative analysis and design. Finally, Dr. Ron Nowaczyk, from the psychology department, educated all of us, including graduate and undergraduate students in the program, and those in other engineering design classes on the mechanics of teaming and collaborative work.

Mechanics

The faculty members met regularly, very often at the onset, and then once a month towards the end of the contract to deal with the various issues that came up. The initial thrust had to establish the undergraduate program and get it going, while at the same time, getting the graduate students started on their research. For the undergraduates, the selection process had to be established, and the program formalized. Financial and other incentives had to be devised and instituted. For the graduates, adequate hardware, software and courseware support had to be either provided, developed or identified. Appropriate journals and conference proceedings had to be acquired, and potential students had to be admitted and hired.

In parallel to the procedural mechanics, institutional mechanics had to be set up. In particular, distribution of funds and of return on overhead, recognition of interdisciplinary research efforts for promotion and tenure consideration, and other such issues had to be brought to the administration's attention.

Accomplishments

This report summarizes our work to date, which has resulted in an increased appreciation for multidisciplinary efforts among our students, colleagues and administrators. It has also generated a number of research ideas that emerged from the interaction between disciplines. Overall, 17 undergraduate students and 16 graduate students benefited directly from the NASA grant; an additional 11 graduate students were impacted and participated without financial support from NASA. The work resulted in 16 theses (with 7 to be completed in the near future), 67 papers or reports mostly published in 8 journals and/or presented at various conferences. **(A total of 83 papers, presentations and reports published based on NASA inspired or supported work)**. In addition, the faculty and students presented related work at many meetings, and continuing work has been proposed to NSF, the Army, Industry and other state and federal institutions to continue efforts in the direction of multidisciplinary and recently multi-objective design and analysis.

The component packing problem was tackled and solved as a multi-objective problem using iterative genetic algorithms and decomposition. Further testing and refinement of the methodology developed is presently under investigation. Teaming issues research and classes resulted in the publication of a web site, (http://design.eng.clemson.edu/psych499/) which provides pointers and techniques to interested parties. Collaborative software was researched, compared and assessed and the results were published. Improved optimization algorithms and thermal systems optimization were developed and continue to undergo testing and validation.

One Ph.D. student working on a thermal systems control problem (mathematical sciences major) applied for and received a NASA graduate student researchers program fellowship. This prestigious award was a direct outcome of the research problems defined by the MDA project.

We did also interest many of our colleagues, and several participated in the grant indirectly by having their students working on topics of interest to us. Among those faculty are: Dr. Wei Chen, Dr. Jason Bokar and Dr. Marvin Dixon.

Shortcomings

The MDA project did identify many hurdles to overcome to fully develop the methodologies. Institutional hurdles, from the resistance of our colleagues to new educational programs and research thrusts, to financial and recognition issues at the College or University level still have to be overcome. Students still have to deliver individual work in the form of a thesis in order to be awarded a degree, yet the multi-disciplinary flavor of the research goes against this individualism. Our college has recognized, and now rewards, faculty for their involvement in multi or inter-disciplinary endeavors. Yet promotion and tenure committees still want the faculty member to individually be recognized by his peers for his or her personal accomplishments. Bean counting at the department, college and university levels rewards individual investigators and does not recognize that the output of the team is far more than the sum of the individual efforts.

The tie to our industrial partners was not as direct as it could have been, mostly because of over-commitment in time both at the industrial partner and at the University. The distance factor did play a role, and would not be an issue in the future if collaborative design tools that are today in their infancy become more widely used.

The following sections detail our work over the past four years. The references in parentheses refer to the papers, presentations or reports related to the topic discussed.

Approach

The Multidisciplinary Design and Analysis program at Clemson University is a NASA sponsored activity which aims at broadening the education of students and better preparing them for the challenges of the real world. The program is designed to fit within the present curricula of different majors, while directing the students to selectively choose free electives, humanities and technical electives to gain the ability to better work in multidisciplinary environments. The program is available to both undergraduates and graduates from various majors. At the undergraduate level, curriculum issues form the backbone of the program, whereas at the graduate level, research issues are more significant.

Undergraduate program

To develop a multidisciplinary undergraduate curriculum, we first had to identify the roadblocks to multidisciplinary designs with the help of our industrial partners. These roadblocks are the inability of students to work efficiently in teams when dealing with large complex problems, and their lack of familiarity or understanding of other disciplines. To overcome these roadblocks, we structured the undergraduate multidisciplinary curriculum. The objectives of the curriculum are to develop multidisciplinary task awareness, to develop team skills and to provide the students with a meaningful multidisciplinary design experience. The specific design of the multidisciplinary program of any participating undergraduate student, while individualized, must meet certain general requirements as well as requirements specific to the MDA program. The general minimum undergraduate requirements are as follows:

- The program must relate the student's major area to the MDA area;
- Courses must be taken under more than one academic department;
- At least four courses or 12 credit hours (not required by name and number in the student's major) must be taken in a coherent program. These must be taken from outside the student's major field;
- A grade of B or better must be earned in each course counting towards the MDA certificate;
- The student's senior design project must be interdisciplinary in nature and be one of the projects supplied by Industry. Students whose major does not require a capstone design course must take a design course in another department and register for a special topics class.

Any student in good standing who is pursuing a degree in one of the participating departments may select elective courses and the subjects of special problems to satisfy simultaneously both the requirements of his or her major degree program and those of the NASA sponsored Multidisciplinary Design and Analysis Certificate. Upon graduation, the student receives both the degree in the major field of study and a certificate attesting to the successful completion of the Multidisciplinary Design and Analysis program.

Students reach different levels of understanding in their courses. We have defined the following three levels:

1. Introductory Subject Material, Casual Understanding
2. Problem Solving Capability
3. Open ended Design Capability

Our objective is to have the students within their disciplines reach level 3 by the time they are at the end of their regular curriculum: i.e., when they are supposed to be enrolled in the capstone design course. Simultaneously, students from cross disciplines should reach level 2 understanding in order to be active participants in the capstone design. Thus, the multidisciplinary design team will consist of a level 2 and level 3 mix of students. (20)

The course requirements, letters to select students and other relevant material are attached in the appendix.

Assessment

The increasing public pressure for institutions to be accountable regarding the effectiveness of their academic programs led to the development of an assessment plan for the certificate program. The undergraduate certificate program has a number of internal and external "customers." These include the students in the program, the faculty teaching within the program, disciplinary faculty who are not teaching within the program, NASA, industry partners, and parents of the students. A major objective was to begin developing an assessment plan for the certificate program that would assess the effectiveness of the program from these different perspectives.

Working with the Director of Assessment at Clemson University, an assessment plan for the undergraduate certificate program has been developed. Because of the unique nature of this program, the assessment plan was submitted as a paper to the annual Assessment Conference of the American Association for Higher Education (AAHE)(64). The paper was presented in June 1996 at the conference in Boston, MA. There was considerable interest expressed from a number of attendees at that conference because of the unique nature of the certificate program as well as the heavy reliance on collaborative and cooperative learning within the courses.

The assessment plan will need further development during the upcoming years as the certificate program develops. We hope to develop a model assessment program that could be used by other institutions that implement a certificate program similar to the one at Clemson. Given past experiences with assessment in general, we can anticipate some resistance from faculty as the assessment plan is more fully developed. It appears that communication and buy-in from all constituencies are needed for assessment to be successful.

One promising product developed from this undertaking has been a web-based tool for classroom management of teams. While the tool is still in prototype form, it enables student teams to provide the instructor with electronic versions of team minutes and agendas, student evaluation of team performance using an objective team performance scale, and student evaluation of other team members. This web-based tool will allow both instructors and student team members to easily evaluate team performance during the academic course.

Team Success as it Relates to Team Member Personalities

(Departments of Psychology, Computer Science, Electrical & Computer Engineering, Industrial Engineering, Mechanical Engineering)

With Psychology taking the coordinating role, all departments involved in the grant have participated in a study examining the relationship between team member personality and team success. One hundred twenty-five undergraduate and graduate students enrolled in one of six engineering or science courses have completed a personality inventory that includes measures of individual conscientiousness as well as openness and receptivity to alternative ideas and viewpoints. These students while working as members of 3- or 4-member teams during the semester completed a questionnaire evaluating team performance. The questionnaire was completed mid-semester as well as at the end of the semester. Team performance focused on team roles including ability to resolve conflict, encourage new ideas, attention to other team members and the team process, participation and leadership. Students evaluated other team members. The relationships among these various perceptions with individual personality were examined as well as with objective team performance as measured by the instructor. The objective was to determine which, if any, relationships exist between individual conscientiousness and openness with different types of role performance as well as overall team performance. The results were published in (64)(66)(68)

Team dynamics

Psychology, Computer Science and Industrial Engineering

Effective teamwork requires groups of individuals to satisfy at least three functions. These include *task production, member support,* and *group well being.* Most teams are familiar with the first function of task production. This function requires the group to complete the assignment provided. In some instances, it may be a written report, a product design or a proposed solution to an existing problem. Teams, however, also take on an existence of their own, and the success in meeting the task production function will also depend on meeting individual group member needs as well as the team's needs. The functions of member support and group well being can facilitate or hinder the team as it works toward completing its task.

Member support includes meeting the expectations of individual team members. These may include opportunities for reward or promotion from the organization, an increase in status, and the ability to participate in decision making within the organization. Group well being focuses on the dynamics of the team itself. Do team members interact well, has workload been distributed among members equitably, is power maintained at the team level, or has it been assumed by individual(s)? Group well being is satisfied if the team environment supports open interaction and communication.

Researchers in group-dynamics have identified a number of different team roles that should be met for a team to be successful. Some of these roles focus on the task and include an initiator, information seeker, clarifier, summarizer and an orienter. Other roles focus on the member support and group well-being functions. These roles include a harmonizer, gatekeeper, consensus taker, encourager, and standard setter. These roles may be fulfilled by separate members, or may be shared by various team members at different points. In many cases, one or more individuals may fulfill more than one role.

Personality types

In recent years, interest in relating individual differences in learning and personality styles to task performance has increased. For instance, the Myers-Briggs Type Indicator has been used to identify different approaches engineers take to tackling a problem. The Myers-Briggs Type Indicator classifies individuals on four intellectual/personality dimensions. We have used the Embedded Figures Test to investigate different approaches taken by computer science students in programming. The Embedded Figures Test identifies individuals as being field dependent (bound by information presented) of field independent (able to go beyond information presented and examine information from different perspectives). Both tests have had some success in identifying valid differences in how engineers and scientists approach problems.

The Problem

The supposition is that teams are often organized to ensure that content expertise of team members is complementary. The focus is on task production. However, little if any attention is given to ensuring that member-roles for member support and group well being are met. The proposed study would examine team functioning in terms of team member personality types and team composition. The hypothesis is that certain personality types lend themselves more to certain team support roles than others do. The success of a team will depend on the extent to which a team has, not only members possessing requisite knowledge and content expertise, but also the necessary support role functions.

Proposal problem.

Existing teams of graduate and undergraduate students in engineering and science courses at Clemson have completed personality inventories. In addition, as part of a sabbatical leave for R. Nowaczyk to work at ICASE at NASA-Larc, NASA engineers and scientists completed forms regarding team performance and team operating styles. At various points during the life of the teams, the teams were asked to review team performance. Analyses of the findings will focus on identifying underlying factors to team success.

The products

The study identified promising personality inventories that predict team member roles in an engineering/design team environment. A profile that distinguishes successful from unsuccessful design teams will be provided, and its ability to distinguish between student and industry teams will be explored. The reliability and validity of the profile will be provided along with recommendations for its use.

Shared Expertise - Background & Problem

Multidisciplinary teams often require individuals bringing different types and levels of expertise to the team environment. The nature of the team product requires expertise from a variety of disciplines. The interaction among individuals is often difficult in the early stages when the team is defining the problem and potential solutions to it. Research in the area of Naturalistic Decision making highlights the need to study the issue of expertise within the specific environment of multidisciplinary analysis for a scientific or engineering problem.

Approach & Findings

Studies were conducted in two environments. The first was the classroom for the team dynamics course. The class consisted of individuals from varying disciplines and backgrounds. A team problem was selected that was sufficiently complex that no student or group of students from one discipline could complete the task. Two classes were asked to develop and modify a web site devoted to illustrating teamwork principles. Students and external observers rated the second attempt at this problem as a greater success than the first. Based on feedback and observations from the first team, the instructor more carefully defined the parameters of the team problem for the second class and also formed teams that guaranteed shared expertise. The lesson learned here was that careful attention to problem formulation and team composition is essential for maximum application of team dynamics in a classroom setting.

The second environment involved the study of NASA-Larc engineers. Based on extensive surveys and team evaluations it was clear that engineering team success is dependent on early team interactions. More than is the case with traditional business teams, engineering design teams depend on problem identification and developing a meaningful set of approaches to problem solution. Teams that were viewed as unsuccessful were often those that did not share different approaches to a problem or were dominated by a single individual or discipline view to the problem. (3)(69)(70)(71) (83)

Laboratory class development in Multidisciplinary Analysis

Electrical and Computer Engineering, Mechanical Engineering

The laboratory class forms an extension of an instrumentation course, which focuses on measurement procedures and transducer uncertainties. Until before the MDA grant, the course had not included a formal laboratory content, and the NASA multidisciplinary project has provided the impetus to put this in place. The class consists of a number of projects based upon measurement and simulation of the near field electromagnetic and thermal interactions between packages located in an air stream whose temperature and flow rate are controlled. The packages are geometrically identical so that measurements in each of the disciplines is accomplished separately and the results combined into one of several strategies aimed at minimizing spacing subject to constraints on the measured variables. Positional constraints such as avoidance of inter-package wiring runs form part of the optimizing procedure. This is important practically but difficult to simulate. However from a measurement's perspective it involves little extra effort and challenges the students to deal with basic practical layout issues.

This laboratory has involved the development of hardware to provide a controlled environment for thermal interactions together with the necessary control systems for airflow rate and temperature. Inter-package capacitance and inductance measurement systems have been developed and the hardware is now usable on a stand-alone basis. The controlling platform is Labview implemented on a 486 PC, which also permits measured data storage.

During the semester, students in the instrumentation course are now involved in completing assignments based upon group project work associated with this laboratory. A simple optimizer has been written in C, which will be extended in the future. A laboratory manual will be written later in the year based upon experience gained from student project work. (6)(59)

Graduate Program

The graduate program is mainly a research effort aiming at developing methodologies and tools to help address multidisciplinary issues in design. Since graduate students have to publish a thesis and papers in order to graduate, research topics were selected to provide the students with specific research issues that can be often dealt with individually, but that are applied to complex multidisciplinary problems. Students often presented their work to their colleagues and faculty team in order to encourage group discussion and the identification of multi-disciplinary issues.

Research issues

<u>Optimizing the Product Development Process through Computer-Supported Internal Collaboration</u>
Industrial Engineering, Psychology, and Computer Science

Background

Current trends in product development reflect a rapid evolution of product and process technology. Competition is becoming more global, with customers placing an increasing emphasis on quality, reliability, and value. Decreasing the time to market is becoming a paradigm of world class product development and manufacturing. To compete in this dynamic environment, organizations are adopting a more concurrent and integrated approach to product development. A starting point for this integration is developing a clear understanding of the customers' requirements so that the products that are developed actually meet the customers' needs. External collaboration with the customers is necessary to develop this understanding of customer needs, but it is not sufficient to ensure development of a product that can be cost-effectively manufactured by the organization. Internal collaboration among design, manufacturing, and other organizational functions facilitates the development of a cost-effective, producible product.

The Need for Internal Collaboration

Producibility needs to be designed into the product through early manufacturing involvement and application of shop-floor expertise, rather than by last-minute design modifications prior to release to production. Design and manufacturing should be able to collectively participate in the development and evaluation of the product and the process by which the product will be produced. However, not all stakeholders are able to provide input to the core product and process development team, due to "time and place" constraints. Thus, there is a need to develop a system that will support internal collaboration and avoid fragmentation of effort.

Objectives

The objectives of this research are to:

- develop a computer-supported collaborative work (CSCW) system in a real-world organization that will meet the needs of the design and manufacturing functions, and to
- increase understanding of the contextual issues encountered in supporting collaboration for product development.

Work Accomplished

Field research was conducted at an AT&T Global Information Solutions facility, responsible for the design and production of desktop and laptop computers. It was then continued at a Ryobi Motor Products facility responsible for the design and manufacture of hand-held power tools. Three methodologies have supported this field research:

- human-centered design, a methodology that stresses an early and continual focus on users and their tasks, empirical testing of prototype designs, and iterative refinement based on the results of this testing to meet explicitly stated usability specifications,
- ethnography, a methodology developed to reveal the tacit knowledge held and shared by individuals within a community, and
- contextual design, an applied ethnographic methodology designed to conform to the constraints imposed by real-world product development organizations.

These methods were used to:

- ensure that the CSCW system to be developed is focused on user needs,
- identify latent, or hidden, as well as verbalized user needs,
- provide a fact base with which to justify CSCW system specifications,
- create an archival record of the needs analysis activity of the development process, and
- ensure that no critical user need is missed or forgotten.

The work focused upon the empirical testing and iterative development of paper-and-pencil scenarios, mock-ups, and prototypes with prospective users of the CSCW system. (14)(15)(16)(17)(18)(19)

Potential Payoffs

We hope to accomplish the following through the conduct of this research:

- Increased collaboration between design and manufacturing for product development.
- Reduced product manufacturing cost.

<u>Development of Design Guidelines for Computer-Based Tools to Support Multidisciplinary Design</u>
Industrial Engineering, Computer Science and Psychology

A research team consisting of faculty and graduate students from computer science, industrial engineering and psychology began work at the beginning of the Fall 94 semester. Weekly meetings were held with the entire team and the graduate students and faculty while graduate students met more often separately during the semester. The team focused on a couple of tasks. The first exploring alternative "GroupWare" applications available for use at Clemson. The focus has been on non-proprietary software. A couple of applications, Groupkit and WScrawl have been installed on systems at Clemson, and we examined the feasibility of using these applications in the development of a GroupWare platform to support the certificate curriculum. The second project was an examination and human factors audit of KMS, a hypertext GroupWare application used by Martin Marietta, one of our industry partners. The human factors audit revealed a number of concerns regarding the ease of use and the learning curve needed to become facile with KMS. Our comments to Martin Marietta showed that they were using the KMS software at a level far above the one our students reached. This enabled us to reconsider GroupWare and computer based tools, and the following resulted:

Background

We have determined that there is a need for effective tools to support designers as they carry out the engineering design process. While a number of computer-aided design tools have been developed and commercialized, these tools can be characterized as:

- relatively limited in their support of the initial, conceptual phases of the design process,
- difficult to "pick up;" that is, extensive training is required in the use of the tools themselves,
- difficult to "put down;" that is, once the designer has made use of the tool, he or she is committed to the use of the tool for the duration of the project activity,
- oriented more to use by designers as individuals than to use by designers as members of a multidisciplinary team.

In the past few years, methodologies for the human-centered design of products and systems, particularly computer systems, have been developed and applied to achieve products that are useful, usable, and liked by their users. We proposed to apply the principles and methodologies of human-centered design to the development of computer-based tools to support the design activities carried out by multidisciplinary design teams. Based on the results of this work, we developed generalizable guidelines for the design of such design support tools.

Objectives

Human-centered design has three objectives. It should result in products that enhance the abilities of the users. These products should also help users overcome their own limitations. And the design of the products should foster user acceptance.

The objectives of this effort are

(1) to demonstrate the effectiveness of human-centered design methodology in the design of a computer-based tool to support the activities of multidisciplinary design teams,
(2) to develop an effective computer-based tool for the support of multidisciplinary design, and
(3) to infer from the results of our design process a set of guidelines for the design of multidisciplinary design support tools.

Approach

We used a phased approach based on the principles and methodologies of human-centered design. The human-centered design methodologies used in this effort include:

(1) visits with multidisciplinary design teams in industry and observations of the designers' activities during the conceptual stages of the product development process,
(2) interviews of prospective users of design support tools,
(3) analysis of designers' tasks,
(4) functional analysis of the reasons for the designers' tasks,
(5) involvement of designers in the development of the design support tool, and
(6) empirical testing of paper-and-pencil scenarios, mock-ups, and prototypes with prospective users of the design support tool.

In the initial phases of the work, emphasis was placed on involving multidisciplinary design teams in industry and the identification of designers' tasks and needs for support in the performance of these tasks. After a particular need was identified for support by a computer-based tool and a concept was selected for providing that support, we shifted our emphasis in the detail design phases of the work to interaction with student multidisciplinary design teams in an academic environment. This provided us with a more cost-effective test bed for the development of the design support tool. The focus of our effort was on the development of a tool that is perceived by its users as usable, flexible, and contributing to the achievement of their objectives in the design process. An important measure of the success of the effort was the users' perceptions of the degree to which the tool supports them in the effective conduct of the design process. Another was the degree to which the users accept and incorporate the tool at their own discretion into their design activities. (23)(25)(26)(27)(34)(35)(36)

Web-tools to monitor team performance and team progress have been developed and are under study now as effective tools for managing teams in a classroom setting. If these tools are successful, it should be possible to develop a set of tools for industry use in monitoring team performance.

GroupWare Platform
(Computer Science, Industrial Engineering, Psychology)

Faculty and graduate students from Computer Science, Industrial Engineering and Psychology are continuing work on developing and/or accessing a computer-supported cooperative work (CSCW) platform to facilitate the undergraduate teams in their certificate coursework. The objective is to have a computer platform for the sharing of team information. Information in the form of text and graphics should be available to all team members for reading, writing, and modifying.

There are no integrated non-proprietary software packages available. While some components may exist on Internet, the functionality of the programs and security of information have been a major impediment. The students evaluated Lotus Notes as a platform to use. While it is proprietary software, its increasing use in the private sector makes it an attractive package for our use. A major roadblock is the installation of sufficient licensed copies on campus to make it easily available to students in the certificate program. We have used a GroupWare package for students in the Teamwork Principles course, and a report was written on the strengths and weaknesses of many of the available programs on the market. (23)(35)

Multidisciplinary Coordination
Mechanical Engineering

An approximation algorithm (two point exponential approximation) that is robust, not discipline specific, simple to compute (first order), yet incorporates a measure of non-linearity of functions (constraints and objective) with respect to the design variables was developed and published. This research considers the multiple disciplines as complex problems that would benefit from approximation to reach an optimum. Since this approximation step is imbedded in the process, using information from the data of the approximation can result be used to coordinate between the disciplines. In the approach proposed (and published), the approximation is used to help estimate the move limits, or range of variability, of individual design variables.

The work consisted in using the move limits to allow individual disciplines to perform optimizations within a confined domain where the alteration of the variables would not affect another discipline. The application considered multidisciplinary problems where the variables were all shared by the different disciplines. A range of move limits is computed in each discipline, and the most stringent limits are used by all disciplines. Once individual optimums are achieved, these optimums are compared in all disciplines to identify the best local optimum within the restricted design space. A new iteration re-computes move limits, and the cycle is restarted. The algorithm has been implemented and was tested on static / dynamic (forced response) problems. Other applications are sought.

A continuation to this work will consider multidisciplinary problems where some design variables are shared, whereas others affect only individual disciplines. An example of such a problem is a structures- control interaction where the controller properties (damping coefficients and location of actuators) affect the controls problem, not the structural static problem. The cross sectional areas of the trusses affect both problems. The same methodology as earlier described will be initially implemented, and its weaknesses and potential assessed. (77)(78)

Decomposition of Design Data
Mechanical Engineering, Industrial Engineering

Complex design data could benefit from decomposition. Such a process typically results in simpler sub systems that are easier to understand and therefore easier to convey the functionality of the complete system. Aspect decomposition (discipline specific), Object decomposition (physical form) and sequential decomposition were investigated. Several methods for decomposition were identified (CI and Branch and Bound, DeMAID and Triangularization). A Modified triangularization algorithm was developed and tested. It compared favorably to results from DeMAID.

This tool resulted in a deeper understanding of the process of decomposition and showed that sequential decomposition can lead to aspect decomposition and simplify designs. The minimization of feedback could be accomplished, and further testing is warranted to validate the methods on large and complex industrial problems.

Further work along this area was used to simplify configuration design problems. Both topics are described in the thesis abstracts. (11)(12)

Virtual Reality CAD/CAE Prototyping System
Mechanical Engineering, Computer Science

The rapid development of computer-based graphics and the availability of virtual reality (VR) equipment present many opportunities in engineering design. It is easy to envision a system in which the designer can put together a design in the same way a sculptor can put together a clay figure. We would see this as the obvious extension to the current computer-aided design/computer-aided engineering (CAD/CAE) systems available today. In this new world, the designer would immediately see the designed object, be able to view it from all perspectives. The designer could also "get into" the object and check ergonomics. Given that the object is something like an airplane, other engineering personnel would be able to develop maintenance procedures, maintenance schedules, and even develop maintenance training. It should also be possible to generate computer models of various components. Such computer models would certainly impact the cost of development.

While such a system is fun to think about, there would be much to developing a computer system that could be used by industry. And the system is not without is research aspects in such areas as computational geometry, constructive solid geometry, database management, and three-dimensional rendering. However, VR has come to the point where we could develop a demonstration system.

There are three specific areas that must be addressed:

1. The interface. The system must be "friendly" for engineers in an industrial setting. Such issues as teaming play a role along with the human-computer interface problems. Some specific problems to address:

    - Virtual painting and drawing. Directly applicable to the CAD/CAM industry.

- Research in haptic feedback. Not only forced feedback due to touching, but research into textures of touch; i.e., being able to "feel" the difference between a smooth surface versus a bumpy one.
- Studying the group dynamics of a virtual design group. How do people interact with each other when they are "virtually" in the same environment, but may be physically distributed?

2. The graphics. We would need to develop three-dimensional primitives to support the work of the designer. Such things are called "virtual environments". Furthermore, there are considerable algorithmic problems to be overcome before VR is a viable mechanism. The development of a "constructive" computational geometry will take from geometry, analytic geometry, constructive solid geometry, numerical analysis and computation. Constructive computational geometry should be seen as an important area of "computational science and engineering".

3. The database management scheme. Something like a modern fighter would take a tremendous amount of space to store the information needed to render the entire aircraft. If a decision is made to produce such an aircraft, then there is important information---bill of materials, for example---that should be directly read from this database. Specific problem areas:

   - What is the most efficient way to deal with such voluminous amounts of information?
   - How do you ensure data integrity in such an environment so that all users share a common view
   - Models. There should be more information in this database than just spatial relationships. There is qualitative information about what shapes define what objects. It should also be possible to directly generate computer models from this database.

We would propose three teams, one per subject area. The interface team should be a sampling of engineers from industry as well as human-computer interface experts from psychology and academic engineering disciplines. The second team again uses the industry input plus computer science elements to understand the underlying primitive geometric and graphical issues. The third team works with the second, but has the direct task of making the CAD/CAE compatible with other needs, such as modeling or bill of materials type processing.

We envision the groups as working closely together, and that most teams would involve both undergraduates and graduate students.

The rapid development of computer-based graphics and the availability of virtual reality (VR) equipment present many opportunities in engineering design.

Our research is concentrated on the use of VR to virtually prototype before building a physical prototype. The work consists in porting CAD files to the VR environment and using the capabilities of that environment to provide feedback to the designer and to allow editing of the CAD files in the three dimensional world.

This necessitated the understanding of the file format used by Rapid Prototyping technologies (.STL format) and its modification to allow ease of editing and efficient visualization. Both algorithmic and interactive correction schemes have been developed and the tool is attracting the interest of industry (GE). (30)(62)(63)

Improvement to Optimization Algorithms
Mathematical Sciences, Mechanical Engineering

The Method of Feasible Directions has been widely used for many years as a design optimization tool, in combination with other numerical methods. In structural optimization, it continues to play an especially important role. In multidisciplinary design and optimization, it is very likely that the method will continue to support many important computational efforts. Thus, we are interested fundamental research on the mathematical and computational foundations of the method. We have efforts to making improvements to the method, including the modifications to improve the convergence rate, which will therefore impact the design and optimization efforts of engineers at NASA and at companies like Lockheed.

These improvement efforts follow three different but related paths.

1) The classical Method of Feasible Directions has been shown to converge globally with a linear rate of convergence. This was done by Pironneau and Polak, and by Topkis and Veinott about twenty years ago. Recently another version of the method, known as the "Norm-Relaxed" method of Feasible Directions has been investigated by Cawood and Kostreva. In that study, it was found that the number of iterations could be decreased (and hence, the number of finite element analyses decreased) if the norm of the direction of movement was not required to be equal to one. The global convergence was demonstrated, but the rate of convergence was left for future research. Now we have conclusive proof that the rate of convergence depends in a strong way on the parameters of the Norm-Relaxed Method of Feasible Directions. These results are derived analytically, and then demonstrated on several structural optimization problems. Comparisons with commercially available MFD codes demonstrate the utility of the new ideas.

2) The Method of Feasible Directions, in its classical form, is composed of two simpler algorithms: (i)direction finding and (ii) constrained line search. The direction finding has always been the solution of a linear program or a quadratic program, with the outcome a single direction vector. These linear or quadratic subproblems always use the first partial derivatives of the objective function and the constraints, and not any higher order derivatives. In the past year we conducted research on the effects of using multiple direction vectors on the Norm-Relaxed Method of Feasible Directions. By the computation of several direction vectors, instead of one, it is possible to get an increase in the convergence of the method. Since the first partial derivative information is costly to obtain, it is advantageous to perform additional calculations (which are not so intensive) to get more improvement from each computation of the partial derivatives. Within the new Norm-Relaxed method we computed several different direction vectors by controlling some parameters inherent to the method. Such computations are independent, and they may be performed in parallel. Such a re-organization of the calculations will necessarily improve the convergence, since one of the considered directions remains the classical one.

3) In certain cases, it is possible to go beyond the usual ground rules of the Method of Feasible Directions and begin to use (or approximate) second order partial derivative information. Such information takes the form of Quasi-Newton updates, used within the Feasible Direction framework. Such an approach will avoid some of the difficulties associated with the Sequential Quadratic Programming Methods, namely, that the computed points do not remain in the feasible set. In fact, the new Norm-Relaxed method can accommodate the well-known BFGS update scheme within a "self-tuning" variant.

Some preliminary research indicates that the results of this study are likely to impact the Method of Feasible Directions very positively. Hence, multidisciplinary optimization would be enhanced as well, especially for those users who are currently using such optimization packages. For users of other methods, what we learn may also have a positive impact, however, a less direct one.

These studies have formed the basis of graduate research in the Department of Mathematical Sciences at Clemson. In fact, the work of Cawood and Kostreva extends the MS. project of Mark Cawood. One Ph.D. student, Jacek Korycki, has been involved in the research, and another X. Chen continues to make progress and improvements. Although the research is aimed at the foundations of the methods, there is a practical outcome, since the methods proposed are generally implemented in computer programs, for testing and comparison with existing algorithms and programs. Such implementations make the knowledge obtained in the study available for non-specialists in mathematical optimization.

Another favorable outcome of the project was the award of a Lockheed summer Internship to J. Korycki in the Summer of 1995. The subjects were decomposition issues, numerical solutions of nonlinear equation systems, and sensitivity issues for coupled systems. A report was delivered to Lockheed personnel, and a presentation was given in August 1995, at the close of the internship. (10)(37)(38)(39)(41)(42)(43)(44)(45)(46)(47)(48)(49)(50)(51)(52)(53)(54)(55)(56)(57)(81)(82)

Incorporation of electronic system design in the MDO Environment
Electrical and Computer Engineering

Introduction

At present the incorporation of electronic packages and systems in a non-hierarchic MDO framework presents severe problems. For the development of lumped or distributed electrical systems many advanced discipline-specific methods are available. Although not usually specified in MDO nomenclature, state variables and constraints are generally readily identifiable, as are the discipline design objective functions for any given electrical subsystem. Apart from mechanical considerations such as c.g. location, shock mounting etc., the principal interactions involving all electrical elements within a complete system are electromagnetic and thermal. It is in designing for EMC and obtaining satisfactory thermal profiles with package movement that makes determination of required coupling functions for the two disciplines extremely difficult.

Electromagnetic Compatibility

As a means of quantifying electrical interactions between spatially distributed subsystems, frequency domain techniques have dominated historically through determination of transfer impedances, admittances or coupling factors. However both near field and conducted interactions are often extremely difficult to quantify particularly in a real environment which involves complex mechanical geometries as well as multiple subsystem electrical interconnections. Determination of the effect of subsystem movement at the design conceptual stage has been a major goal of the EMC community for many years and in principle rigorous solution of Maxwell's equations with appropriate boundary values should yield the required data. A number of approaches using typically the method of moments or finite element analysis have been incorporated within commercially available software packages. However in many practical cases computational bounds are quickly exceeded and the designer must fall back on the classical approach to ensure EMC which is non-algorithmic or heuristic.

Thermal Interactions

Although less demanding than the quantification of electrical interactions, thermal management and the determination of intersystem thermal behavior in a practical system presents a formidable challenge. Assuming the cooling medium is airflow, interfacial behavior, turbulent fluid transport, diffusion and convection need to be considered in formulating a satisfactory model to allow extraction of coupling functions.

Research Plan

The work was divided into two stages, practical and theoretical.

(a) Practical: One laboratory test platform was constructed based upon the use of presently available PC based programmable instrumentation stations currently used as research tools and also in undergraduate electronic measurement/design laboratories. The platform consists of simple moveable electronic packages within either an electromagnetically or thermally controlled environment. The two interaction processes were addressed separately. In the case of field coupling, multiple single frequency radiator/receivers were constructed which allowed relative movement and measurement of coupling factors. Movement and data acquisition is under program control. A second platform was structured similarly but addressed the problem of thermal interactions. Multiple moveable packages geometrically identical to the radiator/receptors but containing programmable heating elements/temperature probes were situated in this second platform. The temperature and flowrate of the airflow through this second platform is controlled and monitored at strategic points. Automatic movement and measurement allow coupling functions to be extracted under a variety of thermal conditions. In constructing the platforms the goal was to maintain as far as possible identical geometry for the thermal and electromagnetic platforms. In this way data from each platform could be combined to form a flexible but simple two-discipline model system which would have missions in both research and MDO education.

(b) Theoretical: The practical program outlined above was intended to provide test bed data to support theoretical treatment aimed at more usefully aligning aspects of electronic design and associated thermal management with the discipline of multidisciplinary optimization. In combination with this treatment work was included directed at including heuristics in both disciplines. (6)(59)

Optimization – Rubber Band packing
Mechanical Engineering

The objective of this work is to develop an optimization algorithm based on a mathematical analogy with a rubber band or an elastic balloon encircling a number of objects. Such an intuitive based algorithm should result in dense packing of components, reaching a local optimum for the single objective component packing problem.

The algorithm is based on the identification of the convex hull surrounding the objects considered, and then on a simple translation transformation in the direction of the resultant of the forces generated by the elastic body encircling the elements. Once contact is achieved, rotation may be allowed since moments would result, and the objects come into some equilibrium which is a local optimum.

The development of the two-dimensional algorithm has been done. A new student is extending the work to three and higher dimensions. The goal is to use the rubber band analogy to come up with a novel robust optimization algorithm.

Optimization – Heat Exchanger multi-objective design
Mechanical Engineering

The goal of this research is to develop a methodology to optimize an automotive heat exchanger. Design of an automotive heat exchanger is at least bi-objective because the amount of heat transferred is maximized while pressure drop should be minimized. These coupled, opposed design goals are achieved by determining the optimal geometric arrangement of the heat exchanger. The optimum configuration is found by coupling a search algorithm with results from computational fluid dynamics (CFD) simulations. Little work has been done using this process except in some aerospace applications. Traditional approaches have considered one of the objectives as a constraint and solved the single objective problem.

CFD is able to model flow details that are responsible for improved designs. It has traditionally been reserved for "high tech" applications because it can be difficult to use and is computationally expensive. Recent developments in computer hardware and software have improved this situation, but some problems still exist. This research identifies some of these problems as they relate to optimization, and aims to encourage the use of these tools for industrial applications.

The generation of the Pareto space of the bi-objective problem is one output of this study. Providing the designer with the Pareto curve will enable him or her to make more informed decision on tradeoff between the two objectives. (24)

Multidimensional visualization
Computer Science and Psychology

This effort supported initially two mechanical engineering classes. Computer science students developed two graphical user interfaces to provide undergraduate students with a better understanding of aerodynamics and strength problems. After this initial multidisciplinary collaboration, the group concentrated on the generation of an interface to display higher dimensional spaces. A 4D viewer was developed and progressed in the following fashion:

a. Working 4D viewer for orthographic projections
b. Experimental 4D viewer for general perspective.
c. Initial implementation of 4D lighting model.
d. Explored algorithms with a lisp interpreter modified to support the viewer.

The 4-dimensional viewer was designed with cognitive experiments in mind. 4D visualization is desirable in engineering when more than two parameters are used to describe a process. Ron Nowaczyk's expertise in cognitive psychology and psychological testing methodology were a perfect match.

The development was initially directly from the text of Foley and van Dam. We implemented a five-dimensional projective viewer using a set of specific vector functions. From the beginning, the goal was to slavishly follow the mathematical formulation so that any extensions to N>4 dimensions would be trivial. The program was documented in the literate programming system called "noweb" which allow us to fully document the program but pass it between students.

The final version of the code allowed for orthographic and general perspective viewing. This version was largely the work of Courtlan McLay who, it might be added, was adamantly opposed to the literate programming style. The earlier versions were the work of Stevenson and John Underwood. Courtlan also attempted a 4D lighting model with color. This version actually produced interesting pictures making the 4D images more accessible.

A side experiment was to have a 4D visualization system, which used a Lisp front end. While somewhat slow at the beginning, experience showed how to dynamically rewrite the code, on a demand basis, to increase performance. (64)

Configuration Design optimization Method
Mechanical Engineering

Problem selection

The problem selected to identify and study multidisciplinary analysis and design issues had to be relevant to NASA, to the industry at large, and had to match our expertise and research interests. Since Clemson University does not have an aerospace department, we selected the component packaging problem. This universal problem is present in aerospace applications (Satellite packing, avionics bays of aircraft, loading of aircraft, etc.), in automotive applications (Under-hood packaging), and in many industrial engineering applications (bin packing, sheet cutting, etc.)

This work was first motivated by curiosity about configuration problems in engineering and how they relate to packing games and theoretical results in this domain. Then a strong motivation for developing a method able to address configuration optimization problems at the system level came from the realization that, in industry, assembly type problems were addressed only by rules of thumb and an engineers' experience. Eventually, the absence of such type of optimization in CAD software, these tools of choice for engineers and architects, confirmed the choice of the subject of this work. Indeed, although these software tools offer the possibility to define products according to customer requirements, which fostered the use of constraint satisfaction mathematical methods as underlying tools, they lack the possibility to tune the product's dimensions in order to reach an optimal behavior at the system level. This is mainly because thousands of constraints to satisfy is a completely different matter than satisfying these same constraints in addition to optimizing objective functions. Including the possibility of optimal assembly design constitutes a challenge that, if met, reduces the gap between pure specific automatic tools and more intelligent tools imitating real design as practiced by engineers.

From a more technical point of view, the absence of work about system level optimal design involving several disciplines or objectives at the same time is a strong motivation for this work. Powerful search methods are emerging from the fields of mathematics and computer science, yet the link with engineering problems is still tenuous. How far can we push these methods? Are they reliable enough for engineering purposes? These are two of the many questions that come to the mind of many managers and engineers who would like to improve the design of their products. Additional motivations fostering this research have been identified. By only moving components, one may improve an already existing assembly with no need for reengineering. This is a usual practice in industry when either a problem must be fixed at the last moment or when a new product must be put on the market with a low developing cost. Engineers do not have time to redesign the full system. Can we help them improve an existing one? Since any real engineering design problem must meet several goals at the same time, multi-disciplinary or multi-objective issues are likely to occur. Volume, balance, and maintainability are among the various objective possibilities that were chosen for this work. The restrictions in terms of objective type, system size and component types are some of the information researched throughout this work in order to help engineers to better practice automated design. Although the different objectives usually conflict with each other, it is believed that there exists a domain of compromised solutions much smaller than the total Design Variable space. Giving the opportunity to navigate through sets of optimal solutions without additional simulations and optimization will widen the range of investigation of engineers. In order to provide the reader with a frame of reference, three industrial applications of configuration design optimization are presented below.

Most of the new cars built today do not present a revolutionary design. One can find the same basic components in nearly all the cars. These include: the motor block, the fan and its motor, the power steering pump and its reservoir, the brake fluid reservoir, the battery, the water tank, the master cylinder, the transmission, the radiator, the distributor, some pulleys and some pipes (Figure 1). The differences are in the presence or absence of one component, in its shape and quality, in the way it is connected to another component and in its location. For example the fan can be an electric fan and require an electric motor with wires connected to the temperature thermostat and to the battery.

If it is a conventional fan it will be connected to the motor block by a belt. When going from one option to the other, only some local differences appear, favored by the need for reuse, "carryover and shared parts" dictated by economical pressure, although a completely new design might enhance the performance of the engine. Hence, in order to stay connected to real needs, instead of providing a tool that will suggest to restart a full design process each time a small component is changed inside the engine, this work focuses on improving the current engine design by just changing the position of the components. Hence, this does not require dramatic changes in the design and manufacturing equipment.

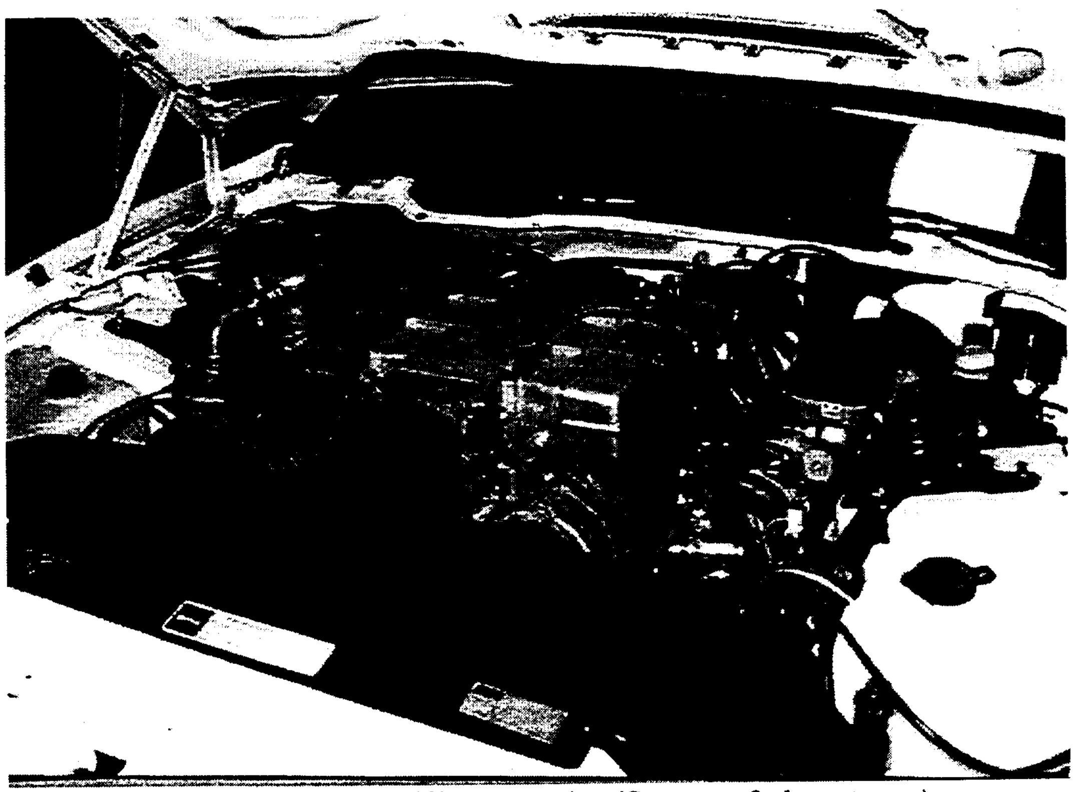


Figure 1. Pontiac GTA car engine (Courtesy Ordernet.com)

Another example is the avionics problem in which the designers must fit a high number of electronic and mechanical components in a restricted volume (Figure 2). These components must be easily accessible for checking and eventual removal. Some of them have additional positioning constraints since they generate heat, which could damage some other components. Finally, the total wiring distance between the interconnected components must be minimized for cost, reliability, and signal speed considerations. A method that suggests how to change components for each different plane will be useless since the electronic suppliers usually propose a catalog with a finite number of components. Hence, proposing different locations for the same part in a different context is a balance between non-optimal systems and completely redesigned systems

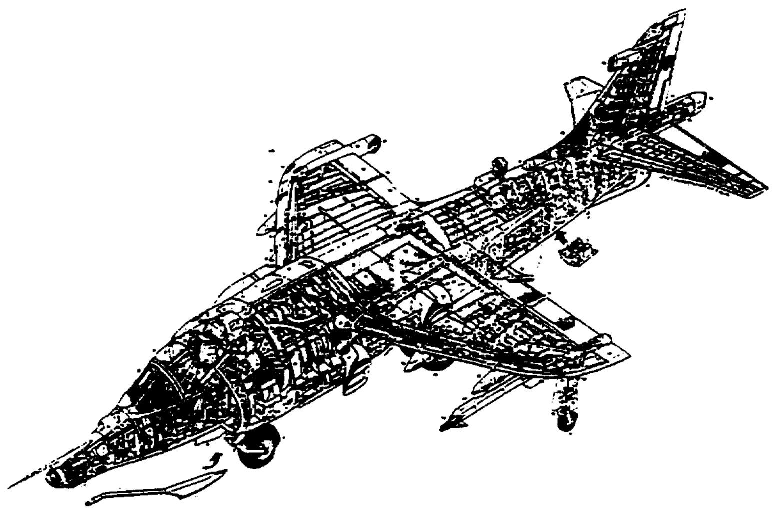


Figure 2. Equipment of a military airplane. (Courtesy Lockheed Martin)

A third example is the design of systems, which are sensitive to the position of their center of gravity. This is the case of payloads for carriers (trucks, airplanes, boats.) Being sure that the center of gravity is at a certain location reduces tire and road wear for trucks, improves the safety when breaking, turning, and reduces the fuel consumption and the driver fatigue. In this case there is no way to redesign the pallets that are standardized (1m x 1.2m or 2m x 2m). Hence, proposing a new pallets distribution is the only way to achieve the goal. This problem increases in magnitude with the design of satellites and rockets components (Figure 3) which are so sensitive to center of gravity location that any error might affect their good functioning and cost hundreds of millions of dollars.

MOPITT - Measurements of Pollution in the Troposphere

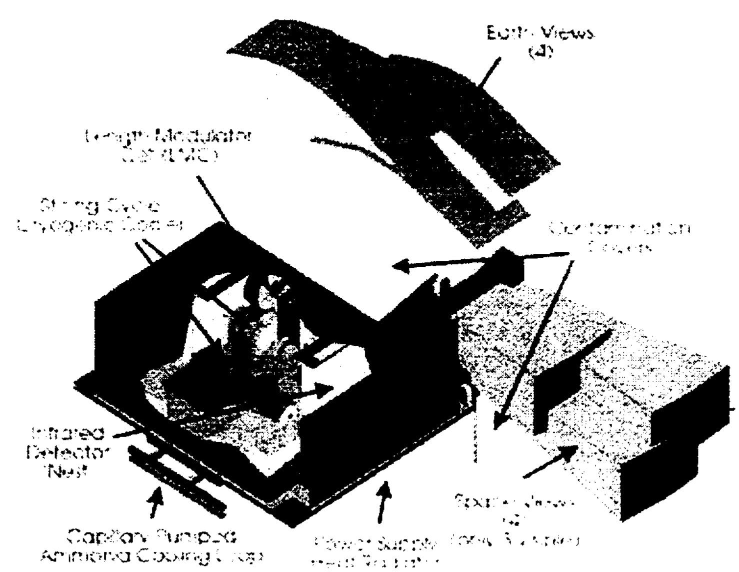


Figure 3. Aerospace component design (Courtesy CSA / Courtoise ASC).

It is important to understand that all these considerations about the placement of objects in space in order to build an optimal system were not the main preoccupation of the engineers as long as major improvements came from other sources (material improvement, new concepts). However, in many engineering fields, revolutionary designs are becoming rare and still improvement is needed in order to stay competitive.

From the scientific point of view, this research was fostered by the absence of general conclusions about the whole family of packing problems in engineering, which are usually formulated as combinatorial mathematical problems applied to components, which have few common characteristics with real components. Most of the research efforts in this domain were focused on producing ever more efficient algorithms to address a specific problem and thus which perform poorly as soon as the components changed. Moreover, using different methods to study a category of problems prevents one from drawing unified conclusions about the difficulty of the task. On the other hand, a more general method, even if less efficient for specific problems, is more widely applicable and thus allows comparisons to be made and conclusions to be drawn. Some recent advances obtained in global optimization might be helpful to investigate engineering packing problems, especially since these problems are Multi Criteria. It is also of interest to establish a classification according to explicit parameters involving the objects and the whole system.

Achievements

The research began with the optimization of the center of gravity positions of rectangles to simulate the payload of a truck and was extended to 3D space, freeform objects and multiple criteria. Note that only with today's technology, computational power, data infrastructures and mathematical methods are we able to begin to address this area of the Digitized Mechanical Engineering Design Process. If this research area achieves its final goal, the consequences on everyday life might be dramatic for all the industrial sectors. Cars, trucks and planes consuming less, buildings being able to endure the most severs hearth quakes, products costing less with enhanced safety, increased comfort are among the many advantages that full assembly optimization might bring.

Today's design process practice shows that companies are heavily relying on CAD/CAM software for creating parts and assemblies. During this process, the automatic tuning of the product parameters (dimensions, shapes, materials) has been, until recently, the exclusive domain of the part design stage. This process is now spreading to the conceptual stage and to the sub-assembly and assembly design of the product. However, the fact that part optimization is less complex, better known and solved more efficiently by specialized methods, prevented the modification of part parameters due to assembly type constraints. It is not rare, in today's applications, to consider part and sub-assemblies as constant whenever system level optimization must be done. This decision simplifies the optimization problem by removing the possibilities of change in the final product. As the engineers keep building the system, constraints appear, reflecting different knowledge fields that link parameters at various levels and thus break the well-established and safe feeling of the hierarchical organization of the full system. Up to now, no fully satisfactory solution exists to optimize these additional relations.

The problem addressed in this work can be summarized as follows: "how can assembly level optimization be performed on industrial projects?" The main goal is to define a method able to address this problem. Thus, the aim is to build a method able to tackle realistic engineering problems, so that free-form components could be taken into account as well as the functional constraints that hold all the system components together. In addition to these first requirements, the need to address multiple goals at the same time is also dictated by realistic engineering design considerations. Translated in mathematical terms, configuration problems can be reformulated as the search for optimal solutions of constrained non-linear multi-criteria optimization problems. The next issue is to generalize the approach to deal with multi-disciplinary problems. The review of the industrial applications showed that no assumptions could be made on the type of components and systems. However, system optimization usually occurred after component shapes and their functional links were settled. From the mathematical representation point of view, the variables (displacements) can be considered as continuous in all cases.

Once this was assessed, three areas were identified for addressing the goal:

- define the complexity of an Engineering Configuration Design Problem (ECDP),
- define the method (called CDOM),
- measure its performance.

In order to address the first goal, a mathematical formulation was proposed that, unlike many formulations found in the literature review, could address any type of components (involving non convex, hollow, sharp edges components). This formulation relies on the use of continuous variables for defining the allowed movements of the components and on penalty functions for penalizing unfeasible configurations. Then, based on the notion of function landscape, four criteria were chosen to answer the first need i.e. evaluating the complexity of the ECDPs. Trend, Roughness, Dilution of the feasible area and Dilution of the solution were defined for any type of C^1 functions and linked to simple characteristics of the ECDPs (size and number of the components, size of the system).

The second goal, the definition of the method, was addressed as finding multiple global extrema of a non-linear optimization problem. A Genetic Algorithm working on population of sets instead of population of individual points was proposed to search the variables space and to provide multiple solutions for three reasons. First, the GA works on several designs at the same time; second, it is able to deal with highly non-linear functions; and third, it capitalizes on the knowledge of its previous trials. The analysis of the complexity classification of some well-known packing problems provided clues for proposing three enhancements to this initial method. First, the penalty should always be combined with the objective function for unfeasible configurations evaluation, then, the use of a Local Search, and Relative Placement contributes to decrease the CDP complexity. Eventually, to increase the chances of the CDOM to escape local minima, an adaptive range strategy was suggested. (28)

Before verifying the validity of these choices, some criteria had to be designed for measuring the quality of the Pareto set obtained using the CDOM. Three criteria were chosen for measuring the quality of the set itself (distance from the extreme planes, distribution of the points, flatness) and two for measuring the performance of the CDOM (speed and repeatability).

A series of cubes CDPs and two engineering cases were submitted to the method for validating the hypotheses and the complexity classification. The conclusion of this part of the study pointed out that the Local Search and Range Adaptation enhancements were the most effective. Relative placement did not bring a clear advantage over the base strategy when dealing with CDPs in which the relative motion is not linked to a functional need. However, this bad performance vanishes as soon as mechanical assemblies are submitted. These modifications help to enhance the performance of the method proposed for achieving the main goal of this study. Figures 4, 5, 6, 7 and 8 show solutions to cube packing, underhood packing and satellite component packing. In all three cases, three objectives are considered: minimize volume, place center of gravity in the middle, and facilitate maintainability. The figures show several Pareto optimal solutions to the problems.

Among the two types of criteria proposed for first rating the CDPs complexity and second for rating the CDOM, only the former were clearly satisfactory and can be reused in further studies. Several criteria are to be rethought for assessing the quality of a Pareto set.

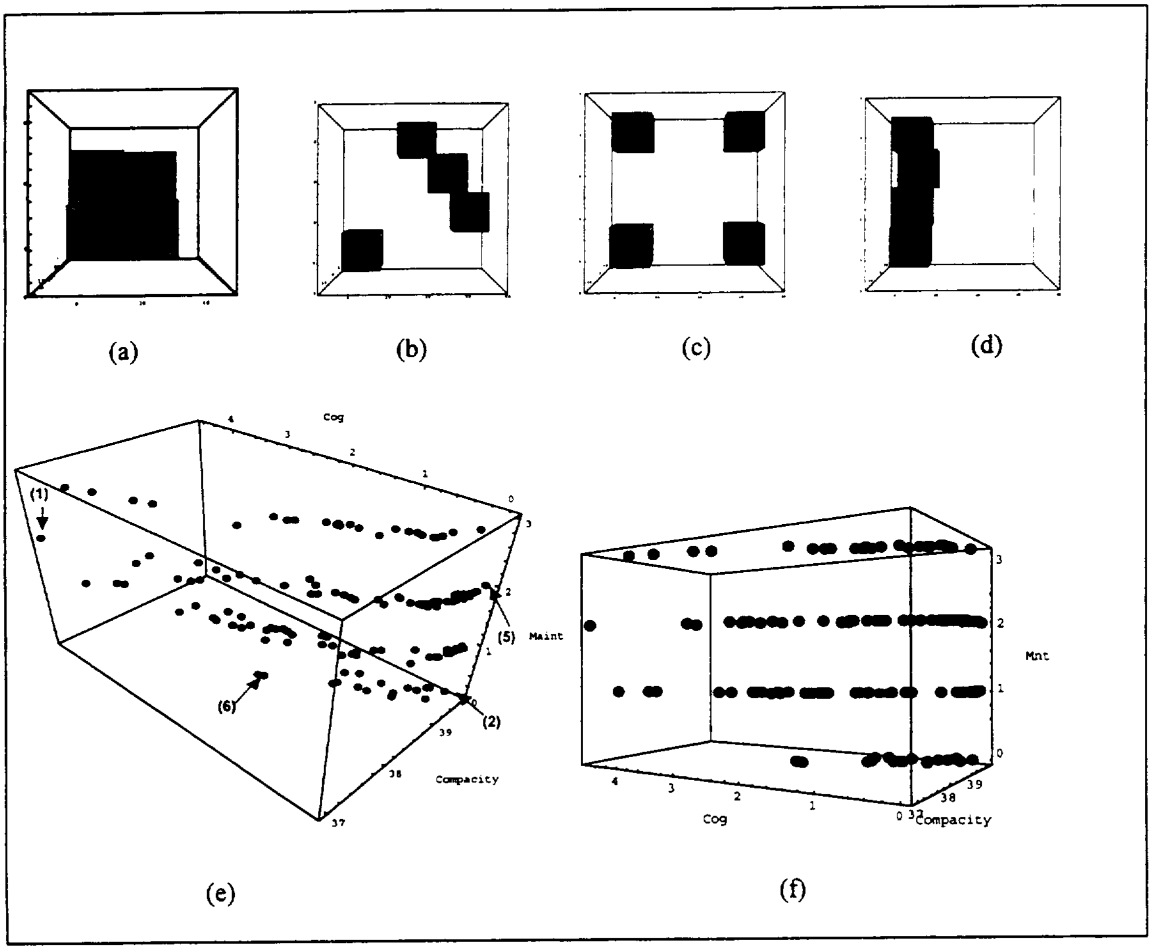


Figure 4. Pareto Packing of Cubes -Left bottom cube is fixed. Each extreme point of the final set (1, 2, 5, and 6) in the objective space corresponds to a configuration (a, b, c and d).

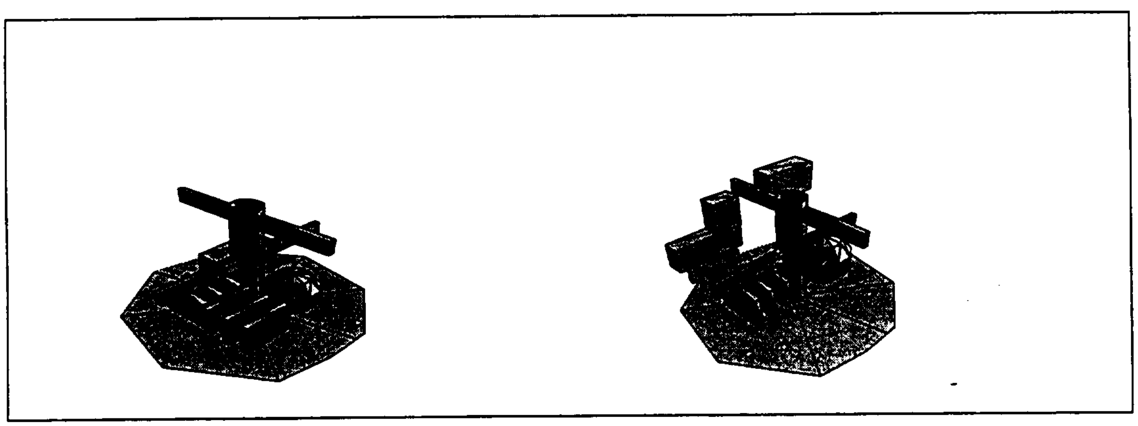


Figure 5. Two extreme configurations for the satellite packing. At left, the maximum compactness configuration discovered by the CDOM. At right, the maximum maintainability configuration.

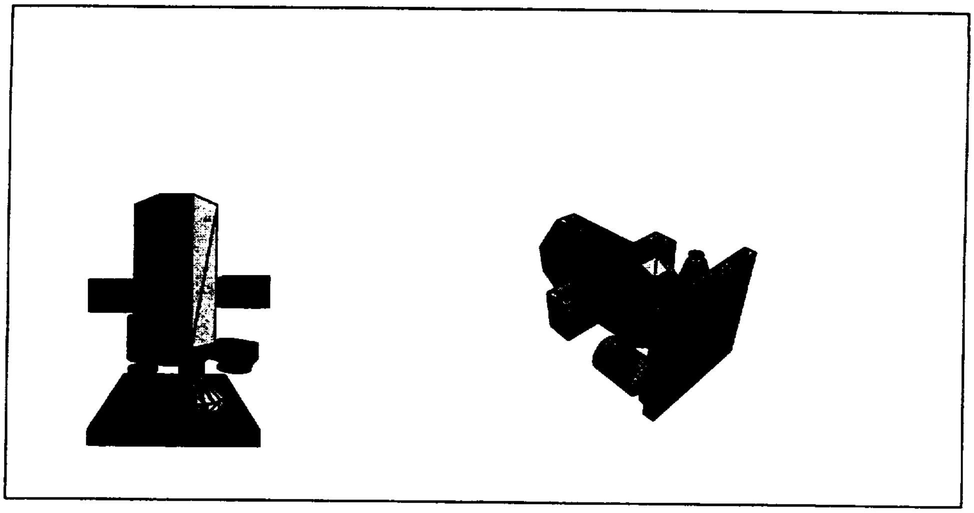


Figure 6. Example of maximum compactness for Underhood problem.

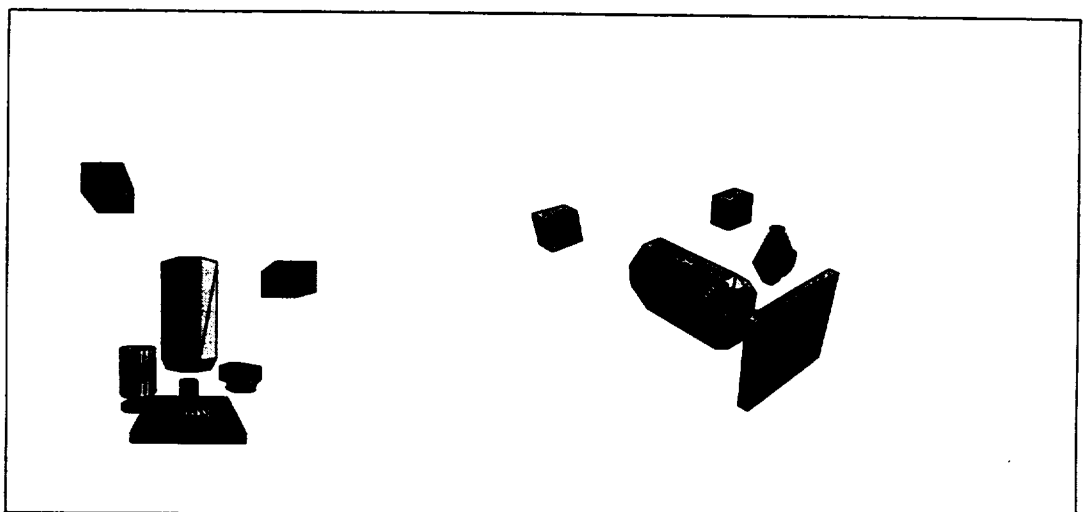


Figure 7. Example of maximum accessibility for underhood problem

Discussion of the Results and Criticism

Even very simple instances of configuration problems are known to be intractable. Hence, trying to tackle the ECDPs with their thousands of variables and their hundreds of non-linear constraints seems out of reach of our possibilities. In this study, it was proposed to bypass the difficulty by working on fully constrained assemblies and authorize some of their components to move by relaxing some constraints. Just like a human can solve to a puzzle matching colors and or shapes, in spite of the near infinite number of different configurations, an engineer can make use of his knowledge of a system to allow a restricted number of components to move "intelligently".

Three different approaches are possible to discover several solutions to a configuration optimization problem. First, sequentially use a method that is able to find a different solution after each run. In our view, this solution does not make use of the information gathered during previous runs and thus is less efficient at producing multiple solutions to the MOP. Second, use a population-based strategy such as a genetic algorithm. The review of the research done in this direction strengthen the conclusion that the primary design of the GA, i.e. clustering the population points around a single value, is contradictory with the goal of this work which is spreading the population along the Pareto set. This remark gave birth to multiple efforts done by researchers in this domain. Third, a new formulation, proposed in our work, brings back the use of the genetic algorithm to its original design, which seems more adapted than any algorithm proposed in this field. The information gathered for finding a Pareto point is implicitly reused to discover neighboring Pareto points. However, many questions remain concerning the use of genetic algorithms for solving multi objective optimization problems: first, questions concerning the relative influence of the non-inferior point definition (characterizing Pareto points) with respect to the set spreading in the objective function design; second questions concerning the preference for wide sets and the conservation of extreme solutions in the population. Eventually, the presence of multiple objectives in the CDP prevented the use of local methods on the objectives themselves (since the local search would have lead to three different points in variable space). The rank based (and thus discrete) objective function was an impediment for using local search on the final objectives combination. Thus, the local search was restricted to the discovery of feasible configurations. The small size of the population might be the reason of the small number of variables that the CDOM is able to handle (premature convergence). This is partially counterbalanced by the iterative use of the GA.

The iterative use of a GA means that the knowledge must be capitalized from one run to the other, otherwise a large part of the iterations' interest is lost. This is achieved, on one hand, by storing the best solution and taking it as an ever-changing reference, and, on the other hand, through the variable ranges restrictions that narrow the GA investigation around the best solutions found so far. This restriction should go along with a reduction of the genome size in order to keep the final precision of the variables constant (and eventually speed up the convergence).

The variable range relaxation was an attempt to make the search less sensitive to premature convergence on local optima while keeping the control of the variables bounds. In GA research, this can typically be done through an increase of the probability of mutation with however one drawback: the difficulty to control the range in which the new design variables will be. The improvement brought by this simple strategy is encouraging and leaves open the possibility to further adapt the behavior of the method.

Implications for Future Research

Several parts of this work are interesting starting points for further research. First, there is no clear correspondence between the Single Objective CDPs (SOCDPs) complexity and the MOPs complexity. The classification proposed relies on the individual study of the objective functions. However, the size of the Pareto set is not only related to the size of the SOCDPs but also to their relative position in variable space.

Second, although the CDOM is designed to work with any type of displacements, rotations were left aside. Considering rotations in the complexity analysis makes the non-linearity of the problem more sensitive to the shape of each component and requires the introduction of additional factors linked to the non-convex aspects of the shapes like holes and shallow parts.

Third, the tessellated surface representations of the solid required more precision. Using an automatic refinement of the tessellation in areas of interest, like the algorithms used for fast visualization in Computer Graphics, might bring more precision in the interference detection. In this same domain, using a quadtree 3D-space decomposition will bring a faster interference checking and will speed up the full computation especially for assemblies with many components. Moreover surface representations do not allow the detection of configurations in which a small object is embedded into a large one.

Fourth, using the relative motion variables with respect to a single reference has two drawbacks. First it does not guarantee that the components remain inside the system, and second it does not allow components to follow complex paths. On the other hand, allowing the engineer to choose the degrees of freedom leaves open the possibility to include knowledge-based systems for incorporating, in the CDP solving process, rules driven by the type of design and the intent of the designer. These rules can then be applied to choose the best design variables in order to achieve the goals. The iterations of the CDOM introduce an additional flexibility in the method that can be used to explore several promising regions of the design variable space. The search can then be easily piloted by higher level rules.

Fifth, complex placement involving several references for the same component was not investigated. It is believed that this case needs a preliminary solving step verifying the compatibility of the position of the object with respect to all its references. A second possibility consists in using again penalty functions, however, in addition to bringing additional complexity to the landscape, this solution is in contradiction with the reasons why the relative placement strategy was proposed.

In the field of Genetic Algorithms the use of population seeding should by tried in order to keep extreme members inside each sets. This should help the solution to spread more widely. Bigger populations must also be used in order to take advantage of the full capabilities of the Genetic Algorithm keeping in mind that each genome is already long.

Finally, CDOM provides multiple solutions each corresponding to an optimal configuration. From this set the engineer must choose a single configuration that will be sent to manufacturing. The choice of this final design can rely on subjective criteria such as aesthetics. How this choice is made is again an area of research that was not covered by the present work.

<u>Summary</u>

In the search for an optimization method able to address the placement of freeform components in complex mechanical assemblies, three goals were achieved. First, a method was proposed, bypassing the problem of solving thousands of nonlinear constraints, which finds multiple solutions to the Engineering Configuration Design Problem. Second, a complexity classification was defined applicable to the Configuration problems and based on simple physical characteristics of the assemblies. Third, several quality criteria applicable to the search of unknown Pareto sets were investigated.

Our approach to the underhood packaging problem dealt with the problem as a multi-objective problem instead of a multidisciplinary problem. However, to solve this problem, we had to rely on mechanical engineering approaches to problem solving, using mathematical optimization techniques and computer graphics. So in reality, three disciplines were used in the solution process, and the faculty from the three disciplines contributed to the solution. With the spread of communication tools, virtual environments, graphics tools, organizational tools such as the ones we researched, multidisciplinary approaches will be easier to handle.

Shortcomings and roadblocks

In our implementation of multidisciplinary issues both in the curriculum aspect of undergraduate students and in the research aspect of our graduate students, we encountered many difficulties. These are highlighted below:

Roadblocks to the implementation

The roadblocks to the implementation of our proposed MDA curriculum were many. The following issues were raised and resolved:

Some faculty objected to offering "yet another piece of paper" from the university. They questioned whether a group of faculty can just offer a certificate to students for taking some courses. We bypassed this objection by working with NASA and our administration, and offering the certificate as a NASA document, endorsed by our administration (Provost's signature). This approach carried more prestige with the students, the employers, and the concept is directly portable to other universities.

Some faculty questioned the additional load created by having students from other disciplines in core courses. We ensured that the selected students had the necessary prerequisites, and controlled the number of students by admitting into the program students with certain grade point averages.

The capstone design projects are "owned" by some faculty. There was a concern that the students would not get an appropriate capstone experience if the project involved many disciplines. We worked with some of our faculty and offered multidisciplinary design experiences initially sponsored by DOE and the Savanna River Site. This received considerable support by industry, students, parents and finally, faculty. Our implementation also received national recognition, and is now a highlight of our program. The capstone design project involves students from at least two disciplines (we have involved Mechanical, Nuclear, Chemical, Industrial engineering, computer science and Math) and has often involved many universities (University of South Carolina, Georgia Tech, South Carolina State, USC Aiken, ...]

Concerns about adding courses to traditional curricula were raised. The certificate is in fact designed to fit within the standard curricula of students, only directing them to judiciously select humanities courses, free and technical electives. In some cases, additional requirements may be needed, but these would be minimal.

Research Roadblocks

Faculty are individualists, they want to work on the problems that interest them, and the effort we had to put forth to overcome some of our natural working habits was significant. Our exposure to teaming skills did help us overcome some of our reservations. Our main roadblock was our inability to get more industrial problems to our students. Distance played a role, and our visits to Lockheed Martin did result in some successes, but not in driving our research. We listened and received feedback from our partners, and then carried on the work relatively independently, then presented it to them. So the team university/industry was very loosely defined. Our schedules and those of our partners were quite full, and it was difficult to get so many people together as often as we should have met. Our partners never refused to set up a meeting and either to come up to Clemson or to welcome us in their plant. They had however many deadlines as we did, and since our project was a side project they had without real budget, they and us tended not to push too hard. Note that several faculty and student teams worked very well together as evidenced by the results we obtained.

From a psychological perspective involving team dynamics, a major roadblock is a better understanding of team interactions in the specific environment of multidisciplinary design and analysis for engineers and scientists. The work with both students and engineers demonstrates a number of unique factors that come into play for multidisciplinary engineering teams. These factors often surface during the early phases of teamwork. More data are needed on the specifics of problems faced by these teams especially in an industry setting. During the tenure of this study we were unable to study teams in an industry environment and relied on student engineering teams and NASA engineering teams.

Future work

Many members of the faculty team and others exposed or participants in our work have used this project as a springboard to attract additional grants and show industry that there is value in looking at some problems from a multidisciplinary aspect. Research grants from various industries and even government (Army TACOM) were obtained. Much of the work proposed or ongoing is an extension to the work started in this grant.

An example of the proposed work is the one on Validation and Verification of Large-Scale Scientific and Engineering Simulations. In an "IEEE Computational Science and Engineering" article (to appear by Prof. Stevenson), what appears to be the sorry state of validation methodology is outlined. This article includes a serious look at the inappropriateness of software engineering practices with respect to scientific computation. Two initiatives are proposed:

a. Theoretical. Dr. Stevenson has been working closely with several people at Sandia National Laboratory, including William Oberkampf who is a member of the AIAA committee on Validation and Verification (V&V) standards. They are identifying several questions that are amenable to mathematical/scientific/(and, yes) philosophical analysis.

b. The IEEE article is most critical of support for development of scientific software. Dr. Stevenson has started work to develop a usable support system for multidisciplinary (science, engineering, and mathematics) development software.

Multidisciplinary Education. In parallel to the research work, Dr. Stevenson is working with the Provost office to develop a proposal for multidisciplinary graduate education at Clemson. The pre-proposal will be submitted to the NSF on 15 April for the "Integrative Graduate Education and Research Training" (IGERT) Program. The outline of the proposal is below. To date, we have 20 companies who have committed to supporting the program.

IGERT Program General Description

Introduction

Clemson University will make an institutional change in graduate education. The program will be interdisciplinary and available to the entire graduate population. The program will also allow for formal continuing education. The student's program will be guided by an interdisciplinary cooperative committee, linking the University, various disciplines and industrial partners. The changes sought will take place over a five year period.

Conduct of the Program

The program uses the computer as a substrate, as the bed to support the student's experiences. The ubiquitous need for computer competency makes it essential we use it as the key coordinating element. The computer and associated resources make the program available in a distance learning/continuing education mode as well as resident campus mode.

The Source of Students

There are three entry modes into the program. The first mode would be the traditional one: undergraduate to masters program. There are two non-traditional modes: (1) people in industry who want to update their skills and receive a masters without quitting their jobs and (2) the engineering technology graduates of South Carolina's community colleges and technical schools.

Industrial Participation

The program should be particularly attractive to industrial partners. They would have first pick of the incoming graduate students. These students would receive ``school-to-work" transition experiences making the graduate very productive when joining the company after graduation. Since the program is open to all graduate students, we must make allowances for students in non-technical majors to gain these transition experiences.

We are working with the Shodor Education Foundation to develop a program. Shodor is a founding partner, along with the National Science Foundation and six other major corporate foundations (The Boeing Company, Dupont, Hewlett-Packard Company, Howard Hughes Medical Institute and Pew Science Program) of the Corporate and Foundation Alliance. The purpose of the Alliance is to revitalize undergraduate education in science, mathematics, engineering, and technology. Shodor itself is a leader in using authentic modeling in science and mathematics education.

Clemson is actively seeking to ``globalize" its curriculum. We will therefore actively seek partnerships with companies with a global outlook. It is our view that companies now transcend national borders and that any educated person must be able to deal with colleagues across the world.

Academic Program

The academic work will center on modeling. The students will observe the traditional sequencing of courses until the beginning of the graduate studies. The masters program will focus on integrating the traditional, subject-focused learning into a body of integrated knowledge. The modeling experiences will use the computer. The doctorate will focus on deeper issues of the computer and its place in the modern world. It is therefore possible for students in the humanities, liberal arts, and social sciences to participate productively.

Course of Study

The students will spend one semester at Clemson learning the fundamentals of correct computation and discipline-oriented programs. The student will then spend alternating semesters at an industrial partner's location working on a real problem of importance to the industrial organization. The solution of this problem constitutes the final portion of the portfolio; in effect, the portfolio replaces the traditional masters' thesis.

Just-In-Time Learning

At first blush, it would appear that the student would have to master many subjects to great depth before this program could be attempted. The answer to this is that we will use the kan-brained approach. Kan ban is the Japanese term for just-in-time manufacturing. Kan-brained means that the material needed to deal with the project at hand is delivered just as it is needed to proceed. Kan-brained is similar to, but not the same as, problem based learning.

Portfolios Instead of Theses

The record of the student's work will be a web-based portfolio. This portfolio will be the student's property. As with portfolios in K-12 and in the fine arts, the student will continually update the portfolio to showcase the student's strengths. The student's work will have been graded by the faculty of the program.

Adminstrative Details

The organization can be administered in many ways. The most obvious --- and therefore least likely to work --- is to create some administrative structure for interdisciplinary studies. Likewise, forcing the studies into an existing structure may be unwise unless that entity has the whole university's backing. It would appear to be the case that the prime requirement is that we not separate the education from the research. Therefore, this speaks more towards an independent institute housing the whole interdisciplinary enterprise. The Beckman Institute at the University of Illinois, Urbana - Champaign is such an institute. To simplify the discussion, we use Institute without being pejorative.

Faculty

The faculty will be adjuncts to the Institute. As such, the Institute does not tenure or promote anyone. The faculty member is still a member of an academic department. Whether or not research faculty are permanent members is a different issue. It is necessary to get a commitment from the academic departments that interdisciplinary activities are co-equal with the "teaching-research-outreach" considerations. [We are also considering the four scholarships in the Boyer report: an alternative model defines four types of faculty scholarship: (1) Scholarship of discovery; (2) Scholarship of integration; (3) Scholarship of application; and (4) Scholarship of teaching.] (Ernest L. Boyer. Scholarship Reconsidered: Priorities of the Professorate. Princeton, NJ: The Carnegie Foundation for the Advancement of Teaching, 1990.)

Institute Curriculum
The Institute will have a core curriculum (a) made up of modules. The content of the core(s) will be designed and developed by the participating faculty. The modules will be designed by faculty and developed as research projects of graduate students in the program. There will be an external review of all developed materials. This external review will consist of (1) local Clemson review by faculty not serving as adjuncts and (2) experts in the field not at Clemson. The small body of permanent faculty will oversee the integration of the modules. The participating industrial partners will have input into developing curricula. It is the job of the permanent faculty to balance traditional curricula standards and the input from industry.

Research
The graduate student will form a committee from the faculty at large at Clemson and will have an industrial member from the participating company. The industrial partner's duty is to testify to the effectiveness of the research. The industrial partner cannot veto the academic committee. Each committee can individually judge the comments of the industrial partner. The student will present a defense, open to everyone on campus. It is desirable to set aside several days during the semester so many students can defend, thereby making it more like a conference than a secret meeting.

The work on team dynamics continues on two fronts. The first is a better understanding of issues involved with shared expertise. Several theoretical models lend themselves to testing of this issue. The best candidate is a "lens" model of behavior, which assumes that a team view toward problem solution is the result of the development of relative "weightings" of the importance of different disciplines to a problem. Unlike traditional business teams where consensus may be the goal, engineering teams may need to empirically identify the potential approaches to team solutions. Current work is directed at studying the changes that occur among team members in terms of perceptions of expertise as the team works toward potential team solutions. This work is focusing on teams with students from different disciplines as they identify possible solutions to multidisciplinary problems.

An other research focus is on the use of computer-supported tools for team interaction. The loss of face-to-face contact for many teams not collocated makes this a crucial area of study. As team members work together, it is imperative that members establish trust and communication patterns that facilitate team development and cooperation. Tools must be designed to facilitate these processes. Empirical work will continue to examine existing tools in an effort to identify ways of improving team communication and sharing of information when a multidisciplinary design problem has been posed.

Continuing along the topic of collaborative tools, another research thrust is in the area of collaborative design tools using equipment such as virtual reality and the virtual workbench. Discussion with other universities is underway, and equipment has been acquired. Human factor issues, design environments and collaboration tools are being thought of. We have implemented a camera in the loop environment to allow the user to see himself or herself in the virtual environment. The university is in the process of getting Internet II, and this technology will be critical for such applications.

In Multiple Criteria Optimization (MCO), the solution of the MCO problem is referred to as the Pareto set. Using Pareto solutions, the decision-maker can have an overview of the possible solutions achievable by the different articulations of his or her preferences. Calculating the whole Pareto set using current procedures (mostly through the use of Pareto Genetic Algorithms as earlier described) is very expensive in terms of computational time. There are issues of distribution of points over the set, issues of preventing the GA from converging on a single solution, which is what the algorithm is designed to do, and issues of computational requirements.

For convex problems, using partial information from the Pareto set, an approximation of the Pareto set can be constructed. The Hyper-ellipse is an easy to tailor curve, which in our ongoing work, is used to approximate the convex bi-criteria optimization Pareto set. Using only two end points and one point in the middle of the Pareto curve, a portion of the hyper-ellipse curve can be used as an approximation of the Pareto solutions in the objective space. For convex bi-criteria optimization problems, unconstrained examples and constrained (linear and non-linear constraints) examples have been tested and the results are well within acceptable error bounds.

Future work will extend the approximations to multiple criteria optimization problems and to non-convex problems. Furthermore, if a desired solution is selected from the approximation curve or hyper-surface, reverse engineering the solution in the design space to obtain the values of the design variables from the values of criteria without redoing the optimization process is being investigated.

This work is also the basis for extending what we learned into a new area, that of designing materials for multiple functions. In nature, heterogeneity is the norm and heterogeneous objects have many advantages, which can be used in numerous areas such as motors, dies (molds), semiconductor circuits, trusses, and airplanes. There are two kinds of heterogeneous objects (i) discrete (ii) continuous (gradient).

Our research objectives are to develop techniques for dynamic heterogeneous object modeling and optimization. Starting from boundary condition (external load and temperature), constraints (mass, stress, and strain, etc), and geometric surface specifications, the modeling techniques are responsible for selecting the locations and types of primary materials from the material database and take care of adaptive meshing and material distribution. Calculations such as stress, strain, and temperature distribution are also carried out in the modeling part. The main task of the optimization techniques is to evaluate different heterogeneous object models and find the optimum that best satisfies our requirements.

Conclusions

The NASA Multidisciplinary Design and Analysis training grant enabled us at Clemson, to learn to better work in teams, to help students (both undergraduates and graduates) become better prepared for the real world environment, and to develop our research areas. This grant has made the difference for many of us, and the results of our work will definitely impact our educational system. The results of the research undertaken will contribute to the advancement of the science and refinement of methods needed to work in a multidisciplinary environment. We will continue along the path, and would like to thank NASA and our industrial partners for the opportunity to work with them. We hope you will consider us for future collaborative or research efforts. For information on any of our ongoing, proposed or future work, please contact Dr. Fadel, Mechanical Engineering Department, Clemson University, Clemson SC 29634-0921, e-mail: gfadel@ces.clemson.edu.

List of Undergraduate participants

- Heather Gerberich - Physics
- Trent A. Kirk – Mechanical Engineering
- David T. Brown – Computer Science
- Lance M. Flood – Mechanical Engineering
- John D. Clayton – Mechanical Engineering
- Michael E. White – Computer Science
- Jennifer Ford – Computer Science
- Tracy Commerson – Industrial Engineering
- Rebecca Hartman – Mathematical Sciences
- Keith Robertson – Mechanical Engineering
- Jay Edwards – Mechanical Engineering
- Ed McDonough – Electrical and Computer Engineering
- J.J. Wagner – Mechanical Engineering
- David Whitehead – Mechanical Engineering
- Philip Carns – Computer Engineering
- Monifa Wright – Mechanical Engineering
- Eric Thome – Mechanical Engineering

List of Graduate Participants

- Sayeejee Tatineni, MS Mechanical Engineering, December 1994 (not funded)
- Scott Best, MS Psychology , May 1995 (funded)
- Venugopal Challa, MS, Mechanical Engineering, August 1995 (not funded)
- Oliver Heim, MS Computer Science, December 1995 (partial support industrial partner)
- Jacek A. Korycki, Ph.D. Mathematical Sciences, December 1995 (partial support industrial partner)
- Michael A. Palazzo, MS in Human Factors Psychology, May 1996 (funded)
- Charles Kirschman, PhD Mechanical Engineering, August 1996 (not funded)
- Melroy D'Souza, PhD, Industrial Engineering, December 1996 (partial support industrial partner)
- Stephane Morvan, MS, Mechanical Engineering, December 1996 (partial support industrial partner)
- Chad Patton, MS Psychology, May 1997 (funded)
- Robert A. Tipton, MS Mechanical Engineering, August 1997 (funded)
- Sunand Sandurkar, MS Mechanical Engineering, August 1997 (not funded)
- Nathan Adams, MS Mechanical Engineering, December 1997 (funded)
- Gary Loughry, MS Electrical and Computer Engineering, December 1997 (funded)
- Robert Baukman, MS, Electrical and Computer Engineering, withdrew, (funded)
- Courtlan McLay, MS Computer Science, December 1997 (funded)
- Amy Ward, Ph.D. Mathematical Sciences, August 1998 (funded)
- Jill Kirschman, MS Industrial Engineering, December 1998 (funded)
- Anna Garrison, MS Mechanical Engineering, May 1999 (funded)
- Grignon, Pierre, Ph.D. Mechanical Engineering, May 1999 (partial support industrial partner)
- Yusheng Li, Ph.D. Mechanical Engineering, ongoing (partial support industrial partner)
- Laura Lancaster, Ph.D. Mathematical Sciences, ongoing (funded)
- Pavlos Miroflatis, MS Electrical and computer engineering, ongoing (funded)
- Todd McKee, MS Mechanical Engineering, ongoing (funded)
- Xibin Chen, PhD Mathematical Sciences, ongoing (not funded)
- David Lancaster, MS, Mechanical Engineering, ongoing (funded)
- Denise Shoup, MS, Computer Science, ongoing (funded)

Papers, reports and Presentations

1) Adams, N. J, and Fadel, G. M., "Constraint Reordering For Multi-Objective Configuration Design" DETC98/DAC-5597, Proceedings of the ASME Design Engineering Technical Conference, Atlanta, GA., September 1998.

2) Adams, N. J. "Constraint Reordering for Multi-Objective Configuration Design" MS thesis, Mechanical Engineering Department, Clemson University, December 1997

3) Barthelemy, J. -F., Waszak, M., Jones, K., Silcox, R., Silva, W. and Nowaczyk, R.H., "Charting Multidisciplinary Team External Dynamics Using a Systems Thinking Approach", Paper No. 98-4939, Proceedings of the 7th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Part 3, pp. 1780-1790, St. Louis, September 1998.

4) Best, P.S. "Perceptual and oculomotor implications of interpupillary distance settings on a head-mounted virtual display". National Aerospace & Electronics Conference (NAECON) 1996 Proceedings, Vol. 1, 429-434. New York, NY: The Institute of Electrical and Electronics Engineering (IEEE) (1996)

5) Best, P. S., "Perceptual and Oculomotor Implications of Interpupillary Distance Settings on a Head-Mounted Virtual Display", MS thesis, Psychology Department, Clemson University, May 1995

6) Bridgwood, M. A., Loughry, G., Claussen, D., Psaier, E. "A Study of Electromagnetic and Thermal Coupling between Electronic Packages" AIAA-96-4072-CP Proceedings of the AIAA/NASA/ISSMO symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, September 1996.

7) Bridgwood, M., Fadel, G. M., Figliola, R. S., Greenstein, J. S., Kostreva, M. M., Nowaczyk, R. H., Stevenson, D. E., "NASA Aeronautics Multidisciplinary Design and Analysis Fellowship (AMDAF) Program Grantees Annual Review Meeting", NASA Langley Research Center, Hampton, VA, December 7,8, 1995.

8) Bridgwood, M., Fadel, G. M., Figliola, R. S., Greenstein, J. S., Kostreva, M. M., Nowaczyk, R. H., Stevenson, D. E., "NASA Aeronautics Multidisciplinary Design and Analysis Fellowship (AMDAF) Program Grantees Annual Review Meeting", AIAA/NASA/ISSMO symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, September 1996.

9) Bridgwood, M., Fadel, G. M., Figliola, R. S., Greenstein, J. S., Kostreva, M. M., Nowaczyk, R. H., Stevenson, D. E., "NASA Aeronautics Multidisciplinary Design and Analysis Fellowship (AMDAF) Program Grantees Annual Review Meeting", Clemson University, May 1997.

10) Cawood M. E. and Kostreva, M. M. "Norm-Relaxed Method of Feasible Directions for Solving Nonlinear Programming Problems", Journal of Optimization Theory and Applications, Vol. 83, No. 2, pp. 311-320, 1994.

11) Challa, V., Fadel, G. M., " Design Data Decomposition" Proceedings of the ASME Annual Congress, San Francisco, November 1995.

12) Challa, V., "A Methodology for Decomposition in Design" MS thesis, Mechanical Engineering Department, Clemson University, August 1995

13) Claussen, D. "A multidisciplinary optimization project on the thermal and electronic coupling of electronic packages," Diplomarbeit thesis presented at the Technical University of Munich on work conducted at Clemson on multidisciplinary laboratory development, February 1996

14) D'Souza M. E., and J. S. Greenstein, "The design of a pictorial control chart for the presentation of process control information to operators on the plant floor," Proceedings of the '94 Symposium on Human Interaction with Complex Systems, Greensboro, NC, pp. 141-155, September 18-20, 1994.

15) D'Souza, M. E. and Greenstein J. S, "The design of a pictorial control chart for the presentation of process control information to operators on the plant floor," Proceedings of the '94 Symposium on Human Interaction with Complex Systems, Greensboro, NC, pp. 141-155, September 1994.

16) D'Souza M. E. and Greenstein, J. S. "A field study of the product development process as a first step in the design of a system to support concurrent engineering," Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting, Philadelphia, PA, pp. 781-785, September 1996.

17) D'Souza M. E. and Greenstein, J. S., "A context-based quasi-experimental evaluation of a computer-supported product development system," Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting, Albuquerque, NM, pp. 370-374, September 1997.

18) D'Souza M. E. and Greenstein, J. S., "An ethnographic evaluation of a computer-supported product development system," Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting, Albuquerque, NM, pp. 739-743, September 1997.

19) D'Souza, M. E., "The Development and Validation of A Computer-Supported Collaborative Work System to Enhance Product Development" Ph.D. Dissertation, Industrial Engineering Department, Clemson University, December 1996.

20) Fadel, G. M., Bridgwood, M., Figliola, R. S., Greenstein, J. S., Kostreva, M., Nowaczyk, R. and Stevenson, D. "Undergraduate MDA curriculum at Clemson University," Proceedings of the 6th AIAA/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, pp. 813-818, September 1996.

21) Fadel, G. M., Bridgwood, M. A., Figliola, R. S., Greenstein, J. S, Kostreva, M. M., Nowaczyk, R. H. and Stevenson, D. E. "Undergraduate MDA Curriculum at Clemson University" AIAA-96-4066-CP Proceedings of the AIAA/NASA/ISSMO symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, September 1996

22) Fadel, G. M., Greenstein, J. S., Nowaczyk, R. and Stevenson, D. "Assessing Collaborative Learning in Engineering and Science Education," Proceedings of the 9th Annual SCHEA Assessment Conference, Myrtle Beach, SC, November 1996.

23) Flax, S., Kirschman, J., Patton, C. and Shah, M., "Studies of Computer Supported Cooperative Work" presentation, Clemson University MDA review, May 1997

24) Garrison, A., "Bi-Objective Optimization of an Automotive Heat Exchanger Using Computational Fluid Dynamics" MS thesis, Mechanical Engineering Department, Clemson University, May 1999

25) Greenstein, J. S., "Cross-disciplinary Education in Design." Presented to the SUCCEED Multidisciplinary Design Workshop, Charlotte, NC, March 1998.

26) Greenstein, J. S. "Introducing human-centered design early in the engineering curriculum," Proceedings of the 39th Annual Meeting of the Human Factors and Ergonomics Society, San Diego, CA, pp. 389-393, October 1995.

27) Greenstein, J. S., 38th Annual Meeting of the Human Factors and Ergonomics Society, Nashville, TN, October 24-28, 1994.

28) Grignon, P. M., Wodziak, J. R., and Fadel, G. M., "Bi-Objective Optimization of Component Packing using a Genetic Algorithm" AIAA-96-4022-CP Proceedings of the AIAA/NASA/ISSMO symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, September 1996.

29) Grignon, P., "Configuration Design Optimization Method (CDOM)" Ph.D. Dissertation, Mechanical Engineering Department, Clemson University, May 1999.

30) Heim, O. "Towards Photorealism in Virtual Environments", MS Thesis, Computer Sciences Department, Clemson University, December 1995.

31) Kirschman, C. F. and Fadel, G. M., "Classifying Functions and for Mechanical Design" ASME Transactions Journal of Mechanical Design, Vol. 120 No.3, September 1998, pp. 475-482

32) Kirschman, C. F. and Fadel, G. M. "Customer Metrics for the Selection of Generic Forms at the Conceptual Stage of Design" Proceedings of the ASME Design Technical Conferences, Design Theory and Methodology Conference, Sacramento, Ca, August 1997.

33) Kirschman, C. F. "Using Functions and Metrics at the Conceptual Stage of Mechanical Design" Ph.D. Dissertation, Mechanical Engineering Department, Clemson University, August 1996.

34) Kirschman, J. S., Kirschman, C. F., Fadel, G. M., and Greenstein, J. S., "The Clemson Intelligent Design Environment for Stereolithography—CIDES 2.0," Proceedings of the Eighth Solid Freeform Fabrication Symposium, Austin, TX, August 1997.

35) Kirschman, J. S., Patton, C. W., and Shah, M. H., "Matching Groupware to User Needs: An Exploratory Study", in the Proceedings of the 35th Annual ACM Southeast Conference, Murfreesboro, April 2-4, 1997.

36) Kirschman, J. S., "The Use of Computer Supported Cooperative Work Applications in Student Engineering Design Teams: Matching Tools to Tasks" MS Thesis, Industrial Engineering Department, Clemson University, December 1998.

37) Korycki, J. and Kostreva, M. M. "Norm-Relaxed Method of Feasible Directions: Application in Structural Optimization" Structural Optimization 11, pp 187-194, Springer Verlag, 1996.

38) Korycki, J. and Kostreva, M. M. " Convergence Analysis of Norm-Relaxed Method of Feasible Directions" Journal of Optimization Theory and Applications Vol. 91. No. 2, pp 389-418, November 1996.

39) Korycki, J. and Kostreva, M. M., "Self-Tuning Norm-Relaxed Method of Feasible Directions", Journal of Optimization Theory and Applications 92, (No. 2) (1997) 311-330

40) Korycki, J. "Lockheed Summer Internship: Final Report" August 1995

41) Korycki, J., and M. Kostreva, Convergence Analysis of Norm-Relaxed Method of Feasible Directions, 15th International Symposium on Mathematical Programming, Ann Arbor, Michigan, August, 1994.

42) Korycki, J., Norm-Relaxed Method of Feasible Directions, Universitaet Kaiserslautern, Department of Mathematics, December 1994.

43) Korycki, J., "Norm-Relaxed Method of Feasible Directions" Ph.D. Dissertation, Mathematical Sciences Department, Clemson University, August 1995.

44) Kostreva, M. M., Chen, X. B., and Korycki, J. A., "A Norm-Relaxed Method of Feasible Directions (MFD) for Solving Nonlinear Programming Problems" AIAA-96-4006- Proceedings of the AIAA/NASA/ISSMO symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, September 1996.

45) Kostreva, M. and Chen, X. B. "Methods for Finding Feasible Points in Norm-Relaxed Method of Feasible Directions", Transactions of International Conference on Optimization: Techniques and Application, (ICOTA), Perth, Australia, July 1998, pp.1127-1134

46) Kostreva, M and Chen, X. B., "A Multi-Directional Method of Feasible Directions", Transactions of World Multiconference on Systemics, Cybernetics and Informatics, July 1998 Orlando, Florida, pp. 352-358.

47) Kostreva, M., Zheng, Q., Zhuang, D. "A Method for Approximating Solutions for Multicriterial Nonlinear Optimization Problems", Optimization Methods and Software 5, 209-226 (1995)

48) Kostreva, M. and Lancaster, L. "A Comparison of two Methodologies in HAZARD I Fire Egress Analysis", Fire Technology 34 (1998) 227-246.

49) Kostreva, M. and Lancaster, L. "Multiple Objective Dynamic Programming", to appear in Encyclopedia of Optimization, Kluwer Academic Publishers, 1999.

50) Kostreva, M. and Chen, X. B., "Global Convergence Analysis of the Algorithms for Finding Feasible Points in Norm-Relaxed MFD", to appear in J. Opt. Theory and Applications.

51) Kostreva, M. and Chen, X. B., " A Generalization of the Norm-Relaxed Method of Feasible Directions", to appear in Applied Mathematics and Computation.

52) Kostreva, M., Getachew, T and Lancaster, L., "A Generalization of Dynamic Programming for Pareto Optimization in Dynamic Networks", to appear in RAIRO - RO (the Journal of the Operations Research Society of France).

53) Kostreva, M. and Chen, X. B., "Methods of Feasible Directions: A Review", to appear in Progress in Optimization II'. Kluwer Academic Publishers, Applied Optimization series.

54) Kostreva, M. and Hartman, R., " Multiple Objective Solution for Tetris", submitted for publication.

55) Kostreva, M. and Ward, A. "Linear Formulation of a Distributed Boundary Control Problem", to appear in Journal of Optimization Theory and Applications.

56) Kostreva, M. and Ward, A. "Optimal Control of a System Governed by an Elliptic Partial DIfferential Equaltion", submitted for publication.

57) Kostreva, M. and Chen, X. B., "Asymptotic Rates of Convergence for SQP-type Methods of Feasible Directions," submitted for publication.

58) Li, Y., Fadel, G. M., and Wiecek, M. M. "Approximating Pareto Curves Using the Hyper-Ellipse" AIAA-98-4961 Proceedings of the AIAA/NASA/ISSMO symposium on Multidisciplinary Analysis and Optimization, St. Louis, MI, September 1998.

59) Loughry, G., "Aspects of Air Flow Control in a very low Velocity Wind Tunnel" MS thesis, Electrical Engineering Department, Clemson University, December 1997

60) Miroftsalis, P., "The Development of Impulsive Noise Detection Systems for use in complex multi-disciplinary Control Systems," MS. Thesis, Electrical Engineering, Clemson University, December 1998.

61) Morvan, S. M. and Fadel, G. M., "Interactively correcting STL files in a Virtual Environment" Proceedings of the Design for Manufacturing Conference, ASME Design Technical Conferences, Irvine, CA, August 1996.

62) Morvan, S. M. and Fadel, G. M., "IVECS: A VR environment for virtual prototyping and editing of STL files" Proceedings of the Solid Freeform Fabrication Conference, Austin TX, August 1996.

63) Morvan, S. M. "Virtual Prototyping, a Step Before Physical Prototyping" MS thesis, Mechanical Engineering Department, Clemson University, December 1996

64) Nowaczyk, R. H. & Underwood, D. "An assessment model for multidisciplinary collaborative learning". Presented at the AAHE 10th Annual Assessment and Quality Conference, Boston, MA, 1995.

65) Nowaczyk, R. H. and Stevenson, D. E. "Perceptual Issues in understanding higher dimensional optimizations" AIAA-96-4100-CP Proceedings of the AIAA/NASA/ISSMO symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, September 1996.

66) Nowaczyk, R. H., Perlow, R., and Palazzo, M. A., "An Examination of Personality Traits and Engineering/Science Student Team Performance" AIAA-96-4069-CP Proceedings of the AIAA/NASA/ISSMO symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, September 1996.

67) Nowaczyk, R. H., and Levi, D. J., "Two Approaches to Teaching Team Skills to Engineering and Science Students" AIAA-96-4068-CP Proceedings of the AIAA/NASA/ISSMO symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, September 1996.

68) Nowaczyk, R. H. "Perceptions of Engineers Regarding Successful Engineering Team Design" ICASE Report 98-9, NASA/CR-1998-206917.

69) Nowaczyk, R. H., "NASA Engineering Team Design: Factors Related to Success" Sabbatical Presentation, Clemson University, March 1998.

70) Nowaczyk, R.H., and Zang, T. "Factors related to Successful Engineering Design Team" Paper No. 98-4941, Proceedings of the 7th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Part 3, pp. 1802-1810, St. Louis, September 1998.

71) Nowaczyk, R. H. "Principles & Processes of Teamwork Course" Special course developed for the MDA program.

72) Psaier, E., "Three Dimensional Automatic Control System in a Low Speed Wind Tunnel," Diplomarbeit thesis presented at the Technical University of Munich on work conducted at Clemson on multidisciplinary laboratory development, October 1996.

73) Sandurkar, S., Chen, W. and Fadel, G. M., "GAPRUS, Three-Dimensional Pipe Routing Using Genetic Algorithms and Tessellated Objects' Proceedings of the ASME Design Technical Conferences, Design Automation Conference, Sacramento, Ca, August 1997.

74) Sandurkar, S. "Three-dimensional Pipe Routing using Genetic Algorithms and Tessellated Objects" MS Thesis, Mechanical Engineering Department, Clemson University, August 1997.

75) Stevenson, D. E., "A Computationalist Looks at the Web and the Internet", International Workshop on Mathematics, Stockholm, Sweden, October 1995; Topic of workshop: how to share mathematical programs and ideas in the new Net world

76) Stevenson, D. E., "Computational Science: Science in the 90s", International Workshop on Mathematics, Stockholm, Sweden, October 1995; Topic of workshop: how to share mathematical programs and ideas in the new Net world.

77) Tatineni, S., Fadel, G. M., "Coupling Through Move-limits in Multi-Disciplinary Optimization", Structural Optimization, Vol. 11, No1/2 pp. 50-55, February 1996.

78) Tatineni, S., "Coupled Multidisciplinary Optimization" MS thesis, Mechanical Engineering Department, Clemson University, December 1994

79) Tipton, R. P., Figliola, R. S., and Ochterbeck, J. M., "Thermal Optimization of the ECS on an Advanced Aircraft with Emphasis on System Efficiency and Design Methodology" Paper No 97. Proceedings of the AIAA/SAE/MDO Conference, Williamsburg, VA, 1997.

80) Tipton, R. P., "Thermal Optimization of the Environmental Control System on an Advanced Aircraft with an emphasis on System Efficiency and Design Methodology" MS thesis, Mechanical Engineering Department, Clemson University, August 1997

81) Ward, A. and Kostreva, M. M. "Optimization of a Controlled Steady State System", Proceedings 7th AIAA/NASA/ ISSMO Symposium on Multidisciplinary Analysis and Optimization, St. Louis, September 2-4, 1998, pp.1650-58.

82) Ward A., "Minimax Optimal Control of Steady State Systems" Ph.D. dissertation, Mathematical Sciences Department, Clemson University, August 1998.

83) Waszak, M., Barthelemy, J. -F., Jones, K., Silcox, R., Silva, W. and Nowaczyk, R.H., "Modeling and Analysis of Multidiscipline research teams at NASA Langley Research Center: A Systems Thinking Approach". Paper No. 98-4940, Proceedings of the 7th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Part 3, pp. 1791-1801, St. Louis, September 1998.

Theses

Coupled Multidisciplinary Optimization
Sayeejee Tatineni, MS Mechanical Engineering, December 1994

Structural Optimization has progressed significantly in the past twenty years and if; is now commonly used in the design of mechanical and aeronautical components. A multitude of optimization programs exists and many have been incorporated in finite element programs and are an integral part of that design tool. Problems consisting of a single discipline like structural, vibrational etc., have been dealt with successfully by researchers. However, very little work has gone into multidisciplinary problems such as the design of an Aircraft, which involves structural, aerodynamic, control and other disciplines. In these cases, sequentially generated optimized solutions of individual disciplines need not necessarily lead to a global optimum solution for a coupled problem. The interdisciplinary effects play a major role in reaching a globally optimized design.

This work is aimed at formulating an efficient procedure for coupling multiple disciplines sensing the effect of one discipline over the other using approximations and move limit strategies. It involves using the information generated from the Two Point Exponential Approximation (TPEA) (which is a first order approximation modified to include a parameter equivalent to the curvature of functions with respect to the design variables) in the coordination procedure for optimization of multidisciplinary problems.

An algorithm, the Best Design Selection Strategy (BDSS) for coupling the multiple disciplines is proposed. The main feature of this algorithm is that the coupling is done such that, parallel analysis without much interdependency of one process over the other is still possible. BDSS uses the rule of "survival of the fittest".

The BDSS algorithm is tested on three problems: beam, three bar truss with lumped mass and ten bar truss with lumped mass, considering stress and displacement constraints as one discipline (static) and frequency constraints as a second discipline (dynamic). Conclusions are drawn and recommendations for future research are made.

Perceptual & Oculomotor Implications of Interpupillary Distance Settings on a Head-Mounted Virtual Display.
P. Scot Best, MS Psychology, May 1995

Little effort has been put into determining the role of interpupillary distance (IPD) in operator perception of virtual environments (VE). The present experiment examined oculomotor and perceptual variables across four IPD settings in a binocular head-mounted display (HMD). The subjects wore a HMD for 15 minutes while manually estimating the size of two-dimensional objects in a VE. A within-subjects design exposed each subject to four different experimental conditions: (1) the subject's anatomical IPD, (2) 5.0 cm (the minimum possible), (3) 6.3 cm (adult mean), and (4) 7.4 cm (the maximum possible). Task-induced adaptation of far acuity and accommodation and vergence were measured. After the task, each subject completed a survey that indexed the severity of any HMD-induced fatigue. Size judgments were not affected by IPD condition. Further, IPD settings did not influence adaptation of dark vergence, of dark focus, or of far binocular acuity. However, in the 5.0 cm and 7.4 cm IPD conditions, subjects reported significantly more fatigue than in the anatomical and 6.3 cm conditions.

These findings suggest that IPD settings do not influence size perception in a VE, but are related to operator comfort. The implications are examined in reference to training procedures and entertainment uses of virtual environments.

A Methodology for Decomposition in Design
Venugopal Challa, MS Mechanical Engineering, August 1995

Efficient design is very important for any product or system as 7()~80% of the life cycle cost is determined at the design stage. As many of the engineering systems or products are large and multi-disciplinary, ways to deal with the complexity have to be investigated. The design, if complex, can be made simple and efficient by breaking down (decomposing) the original complex problem into smaller sub-problems. The solutions to each of these simpler problems, when combined, would represent the solution to the original problem. These sub-problems are typically associated with disciplines where experts have developed efficient discipline specific solution methods.

The inter-relationships among the variables belonging to the different disciplines hinder decomposition. The aim of this research is to implement an algorithm that orders the variables Involved into groups of sub-problems based on disciplines. These sub-problems can then be analyzed in a logical order to complete the overall design resulting in a faster product or system design and development.

The research presents various decomposition methods available in the literature. It stresses the difference between Group Technology methods (assignment problems) that aim to identify bottleneck processes or variables but do not focus on the sequential aspect of the design, and sequential methods (scheduling methods) that aim at minimizing feedback and iterations. An implementation of a scheduling algorithm is described and applied to three test cases. Conclusions and recommendations are drawn.

Norm-Relaxed Method of Feasible Directions
Jacek Korycki, Ph.D. Mathematical Sciences, August 1995.

This work is focused on a norm-relaxed method of feasible directions for solving inequality-constrained nonlinear programming problems. This is a variant, recently proposed by Cawood and Kostreva, of the popular Pironneau-Polak algorithm. The novelty is in the use of an ellipsoidal norm to restrict the length of the direction computed by the quadratic-programming sub-problem. The ellipsoidal norm is generated by a scaling matrix, which can be updated in order to speed up the convergence. Theoretical investigations include: global convergence analysis; analysis of the rate of convergence; and especially, the dependence of the quotient rate of convergence on the scaling matrix when using both exact and inexact line-search techniques. Tight upper bounds on the constants of linear convergence have been obtained using convexity assumptions and using assumptions relative to the second order sufficiency condition for local minima. When reduced to a special case with the scaling matrix being the identity, these bounds are sharper than earlier results of Pironneau-Polak and Chaney. The analysis shows that, although the method is only linearly convergent, the scaling matrix can substantially influence the constant of linear convergence. Computational research was focused on designing update techniques for the scaling matrix in order to reduce the number of steps required for convergence. These techniques include BFGS updates and tuning of a scalar weight in a way characteristic of trust region methods. Also, a multiple-directions approach was studied and proved to be successful. The method was tested on standard problems from the collection of Hock and Schittkowski as well as on structural optimization problems involving finite element analysis. It was verified that the proposed techniques bring noticeable computational savings when compared to the classical Pironneau-Polak algorithm. The method was also benchmarked against two popular optimization packages implementing other variants of the feasible direction method, CONMIN and DOT. It was found that the new code performs better than CONMIN and comparably to DOT on structural optimization problems.

Using Functions and Metrics at the Conceptual Stage of Mechanical Design
Charles F. Kirschman, Ph.D. Mechanical Engineering, August 1996

Function has been the focus of much design research. This work pulls together many of the previous research ideas and builds on them by creating a means for the designer to work with function during preliminary design. This is accomplished by providing a framework for function-based design and a technique for comparing designs at the functional level.

The framework for functional design is largely met by a taxonomy of elemental mechanical functions. The taxonomy is based on the four mechanical engineering concepts of Motion, Power/Matter, Control, and Enclosure. From these categories, each function is described using a sentence structure. The taxonomy augments current functional decomposition schemes by providing a stopping point. The taxonomy also provides a common language for designers to discuss function which mitigates the semantic difficulties often encountered when describing functions. Mother benefit is that the taxonomy reduces the information set, permitting software development and malting it useful as a teaching tool. Furthermore, many elemental functions have common forms associated with them. This property enables the designer to choose from an automated list of forms.

The customer driven metrics *Pleasure, Protection* and *Inverse Cost* form the basis of a technique to choose among the forms to fulfill a function. The comparison technique is based on multi-attribute utility theory to evaluate tradeoffs and rank alternatives. By using this technique, the designer is able to evaluate preferences of generic forms without specific performance levels. Also, this technique reduces the size of any particular decision so that the designer need not consider many factors at one time. A second technique uses the metric values developed for each function/form pair to rank subsystems when a single form cannot be chosen in isolation from other forms. The trimmed mean describes the merit of one system versus another while standard deviation provides a relative measure of the components of a system. All of these concepts were implemented in a software system, which validates the work.

Virtual Prototyping, a Step Before Physical Prototyping
Stephane M. Morvan, MS, Mechanical Engineering, December 1996

Free Form Fabrication (FFF) allows Computer Aided Design (CAD) systems to output solid 3D objects. Currently, this technology is weakened by the link between computers and FFF machines: the .STL file. This file contains a series of triangles forming the skin of the object to be prototyped and is subject to errors that interfere with the fabrication process. Some of these errors include: holes, cracks and gaps in the case of missing triangles, triangles not following the outward normal rule, and bad tessellations with a rough surface compared to the original CAD model. Since a prototype reflects precisely the evolution of a concept within a design cycle, a systematic inspection/verification/correction of the .STL file is essential.

A system is proposed for the preprocessing of these files. The system detects errors in .STL files and allows triangles to be added, removed, reversed or offset. The .STL object is viewed in a smooth shaded view that can be transformed (rotated, zoomed and panned) in real-time on the screen. Also, the tessellation's quality is assessed with freeform surface interrogation techniques where the smoothness of a surface is inferred from the surroundings' reflection upon it. Finally, several tools allow the object to be virtually prototyped: these include a slicing plane performing a 'cut' in the part; a transparent mode allowing the part to be rendered as if it was translucent to light; and finally, a tool helping verify the number of merged solids in an .STL file. The added value of this system for a built artifact is the ability to use advanced real-time imaging techniques to virtually prototype a part, complementing CAD systems and FFF machines.

The system was developed as a stand-alone application named IVECS A virtual reality based user interface was assessed to enhance the overall ease of use of the system. The system allows .STL files to be edited and corrected. Also, using the freeform surface interrogation techniques helps quickly understand a part's geometrical features. A file which presented 600 problematic facets (out of a total of 4200) was corrected in two hours.

The Development and Validation of A Computer-Supported Collaborative Work System to Enhance Product Development
Melroy D'Souza, Ph.D. Industrial Engineering, December 1996.

The variety of different products in the marketplace today has made the task of a product development organization very complex, because many criteria must be taken into account when developing a product. Information must be available to the stakeholders of an organization when they need it, or valuable time will be lost. A more cooperative effort involving faster and more simultaneous processing of information is required. In addition, the success of an organization hinges on its ability to dynamically incorporate lessons learned and to make optimal use of its corporate product development history with each new project. There is a need for enterprise-wide electronic archives that may be readily and efficiently accessed by all functional areas throughout the product development process.

The main focus of this research was to identify and understand critical issues that play a role in the development of a computer supported collaborative work (CSCW) system, and to use a context-based ethnographic methodology to develop a CSCW system in an actual industrial organization that would meet the organization's growing need to share information among manufacturing, design, and related areas. It was hypothesized that this would result in a more integrated product development process, which would reduce product development time and positively affect the development capability of the individual users and the organization. Three phases formed the basis of this research. The first was an exploratory study in the product development organization that sought to identify critical issues that play a role in the design and implementation of a CSCW system. In general, the results from this study suggested a need for documentation of critical information, increased communication of that information, and alternatives to paper-based communication.

The second phase dealt with the design and development of the CSCW system in its intended use environment and the formal evaluation of the research hypothesis using a quasi-experimental design. This experiment compared the performance of eight different subgroups using the CSCW system with their performance using the existing system. Task completion time, non-value added (NVA) time, and certain subjective measures were recorded for each of the two systems tested. Despite their minimal experience with the CSCW system, the subgroups took less time to perform five of the eight tasks with the CSCW system than with the existing system. The time saving was primarily a consequence of a substantial reduction in NVA activities. The mean percentage of total task time devoted to NVA activities dropped from 44% with the existing system to 6% with the CSCW system. Users also rated the CSCW system significantly better than the existing system in terms of the subjective measures.

Phase three, an ethnographic evaluation of the CSCW system, focused on its effectiveness and acceptance in its intended use environment. Users were asked to use the system for a period of 60 business days to perform actual product development tasks. The frequency of use of the system and certain subjective measures were recorded at fixed intervals during this phase. The highest usage was during the fourth (final) evaluation period, and the lowest usage was during the second. Users tended to agree that the development capability and the potential benefits to the organization of the CSCW system exceeded those of the existing system. The results of this phase appear to support the use of a context-based ethnographic approach to developing features of a CSCW system that meet not only functional needs, but also socio-technical ones.

The development and implementation of a CSCW system in an actual organizational setting and users' positive evaluations of it relative to the existing system have demonstrated the potential of CSCW systems to enhance the product development process. However, implementing the CSCW system took longer than anticipated, due to organizational and socio-technical factors that inhibited adoption.

This research has shown that context-based ethnographic methodology can be a powerful tool in capturing critical information for use in the development of a CSCW system in an industrial environment. Through the ethnographic evaluation, it was possible to determine tasks that were feasible and others that were inappropriate for integration into the CSCW system. The evaluation methodology also identified issues that restricted the adoption of the CSCW system. Strategies for adoption that deal with these issues are proposed. They may serve as guidelines to designers of future CSCW systems.

Thermal Optimization of the Environmental Control System on an Advanced Aircraft with an emphasis on System Efficiency and Design Methodology
Robert Paul Tipton, MS. Mechanical Engineering, August 1997

Two methodologies for analyzing and evaluating the environmental control system (ECS) on an advanced aircraft have been developed in this study in an effort to determine the optimum ECS design configuration. First, the conventional detail analysis used concept of energy conservation to calculate fuel penalties imposed on the aircraft resulting in a total gross takeoff weight (GTW) associated with certain ECS performance requirements. Next, the system efficiency analysis used the second-law concept of entropy generation to determine the total irreversibility associated with a particular system design. This irreversibility was then related to the wasted energy, or excess fuel used up in the process of satisfying the cooling requirements of the ECS.

Simplified analytical models of the ECS have been developed for each method and compared to determine the validity of using the latter to facilitate the design process in optimizing the overall system for a minimum gross take-off weight (GTW). A sensitivity analysis has been performed on both methods to determine the effects of both heat exchanger effectiveness and coolant mass flow rate on such results as fuel penalty and entropy generation number associated with the various subsystems, which constitute the ECS. Comparisons between these results have demonstrated the importance of taking into account component or system efficiency in addition to the imposed fuel penalty when optimizing the ECS based on minimum GTW. However, further research is necessary to determine whether this second law approach is advantageous for the integrated systems design engineer.

Three-Dimensional Pipe Routing using Genetic Algorithms and Tessellated Objects
Sunand Sandurkar, MS Mechanical Engineering, August 1997.

Pipe routing is the technique of developing collision-free routes for pipes between two locations in an environment scattered with obstacles. In the past, research has been primarily focused on the use of deterministic optimization techniques to derive the optimal route. Computational efficiency of deterministic techniques is low for highly nonlinear and sometimes discontinuous problems like pipe routing. Besides, due to limitations in the representation of 3D geometry, the shapes of obstacles have been restricted to primitives. In this research, a novel approach to overcome these limitations is presented.

A non-deterministic optimization approach based on Genetic Algorithms is proposed to generate pipe routing solution sets with a robust searching efficiency. Representation of the objects and pipes in the tessellated format offers huge benefits in computation as well as adaptability. The versatility of the current approach and its ability to accommodate and efficiently solve problems involving 3-D freeform obstacles is demonstrated.

A preliminary design model is applied that incorporates the basic objectives and constraints. Based on the promising results of this model, an improved design model is developed involving a few real engineering constraints and objectives. A simplified model of the automobile assembly is generated using this technique. The solutions obtained for this assembly problem are useful in validating the efficiency of the current research approach to solve pipe routing problems.

Constraint Reordering for Multi-Objective Configuration Design
Nathan J Adams, MS Mechanical Engineering, December 1997

Configuration design is the process of placing components, without altering their shape or connectivity, into an available space, while satisfying various spatial constraints, such as no component overlap. Minimizing the volume occupied by the components and or maximizing the accessibility of the components are just two examples of the many objectives that can drive a configuration design problem.

For complex configuration designs, there can be many objectives, which can impose spatial constraints among the components and increase the design complexity, cycle cost and time. An iterative procedure becomes necessary to reconcile these spatial constraints. To reach solutions that are optimal, these constraints must be reordered. Successful reordering can make complex configuration design problems easier to solve by minimizing the iterations necessary to reach an acceptable solution. Minimizing iterations translates into faster convergence, and thus savings on time and money.

The goal of this research is to propose and implement a methodology that can manage the propagation of spatial constraints in complex configuration design problems. The proposed methodology utilizes objectives from the concurrent engineering methodology along with principles from the decomposition methodology and applies them to a problem in configuration design. Representative examples are shown and results and conclusions are drawn.

Aspects of Air Flow Control in a very low Velocity Wind Tunnel
Gary Loughry, MS Electrical Engineering, December 1997

When working on an interdisciplinary project involving all aspects of component packaging, it is necessary to do some practical measurements. The particular aspects of interest are electromagnetic, thermal and physical. In order to study quantitatively the thermal interaction of components, it is necessary to control the environment in which they are being studied. Dr. Bridgwood and Dirk Claussen built a draft tunnel, (very low velocity wind tunnel) in which to measure thermal and electric coupling. The draft tunnel has nine twelve-volt switching fans to provide the airflow, and PVC plastic pipe for flow straighteners. Our next project was to control, and measure accurately the flow of air in the tunnel.

For flow measurement, we designed and built a constant temperature difference thermistor anemometer. By holding the temperature difference constant, we hoped to keep massflow constant with changes in temperature. Initial calculations indicated that due to the nonlinear characteristics of thermistors, a bridge would not keep the temperature difference within 10% over a 100C range. The next technique attempted was to measure the ambient temperature and calculate the required temperature and resistance of the heated thermistor with a digital circuit. The thermistor was then kept at the required value using a feedback loop, and the power dissipated was a measure of airflow. After building a successful digital circuit to compensate for temperature, we took another look at bridge circuits with the intent of using thermistors made of different materials and possibly series of parallel transistors. We found that we could build a bridge circuit that would compensate the nonlinear thermistors within 0.5C over a 100C range.

The goal of linearizing the relationship of power to flow rate by altering the airflow was not achieved for flow rates below 100 feet per minute. It appears that linearizing by altering the airflow is not practical, and therefore the output, power, will have to be linearized.

The other portion of the project was controlling the speed of the fans. The fans would not run at significantly reduced speeds by reducing their supply voltage, because they use internal electronics and switching to control the coil current instead of brushes as do standard DC motors. Many electronic devices automatically shut off below a certain voltage; that may be the case here. To counter this, we fed the fans with pulse width modulated 12V, and used three term controllers to set each fan to the desired mechanical frequency. Each fan has its own controller, and therefore fans can be set to run at the same speed or at different speeds.

Minimax Optimal Control of Steady State Systems
Amy Ward, Ph.D. Mathematical Sciences, August 1998.

In recent years, engineers have become increasingly concerned with operational and performance issues. This concern has led to the incorporation of mathematical optimization routines into engineering design techniques. The optimal configuration of objects in a domain is one area of application. This work will focus on optimal configurations for objects in a two-dimensional steady state system. The three models considered are formulated as optimal control problems and feature boundary controls, distributed controls, state constraints and minimax objective functions. Although the standard results of optimal control theory are not directly applicable and necessary conditions for optimality are difficult to define for minimax problems, minimax objective functions seem to be a natural choice for application. In each of the three models, a lower bound describing a feasible operating temperature, becomes a constraint on the state of the system. In addition, a boundary control represents the heat generated by an external source. In the third model, the configuration of the objects in the domain is described by a distributed control.

The continuous feasible solutions of the optimal control problems are approximated by finite dimensional solutions constructed with the finite element method. The finite element approximations lead to a family of finite dimensional optimization problems, which may be solved with non-linear programming methods. However, since the minimax objective functions are easily linearized, these problems are reformulated and solved with large scale linear programming methods. In general, linear programming methods are faster than non-linear methods and capable of solving much larger problems. With the large linear systems associated with finite element approximations, both speed and size capabilities give linear programming the advantage over non-linear programming. The application of maximum principles to the state of the system allow the linearized minimax objective functions to be reduced from constraints over the entire domain to constraints over the boundaries, thereby reducing the number of constraints in the linear programming formulation. The numerical solutions generated by these two methods give insight into characterizing the optimal solutions of the control problems.

Discussion is also given of the existence and uniqueness of the solutions to the optimal control problems as well as the convergence properties of the finite element approximations to the continuous problems. Given a boundary control and a distributed control, the states of the systems exist and are unique. However, the minimax control problems do not, in general, have unique solutions. While multiple solutions are advantageous to the design engineer, convergence of the sequence of finite dimensional approximations to the optimal continuous controls cannot be shown for these problems. Describing the set of optimal solutions is difficult without convergence or optimality conditions. However, the dual solutions and optimality conditions of the linear programming problems are shown to characterize the set of optimal solutions.

The Use of Computer Supported Cooperative Work Applications in Student Engineering Design Teams: Matching Tools to Tasks
Jill S. Kirschman, MS Industrial Engineering, December 1998.

There are a number of methods that are employed to facilitate communication within teams. Sometimes a group can be brought together at a single location for a meeting. Although this is probably the most effective means of communication, often this approach is too expensive, too time consuming, or both. So alternative approaches have been developed. One recent advance is the use of networked computers and "groupware" to support collaboration (Computer Supported Cooperative Work or CSCW).

The purpose of this investigation was to identify whether CSCW tools are useful and usable for completing particular design-related tasks of student engineering design teams. This research compared four CSCW meetings against each other as well as against a traditional face-to-face meeting for three design-related tasks in terms of speed of performance, quality of performance and subjective user satisfaction. Based on the results of a user survey and observations, three tasks were chosen for study: brainstorming, co-editing reports, and negotiating. Based on the survey results, as well as previous studies, it appeared that audio, video and application sharing would be the most useful groupware tools for completing these tasks.

For this study there were four experimental groups and a control group. Each of the five groups was composed of four three-person teams. All team members were students enrolled in courses that required group work. A 2 (Video) x 2 (Sharing) factorial design plus control (Face-to-face) was used. Teams in each group completed all three tasks in one of the five conditions. Two experimental groups were provided only file-sharing, while two groups were provided application-sharing capability. Similarly, two groups were provided access to video and two were not. A face-to-face control group permitted comparison with the performance of a co-located group. Each of the three tasks had a specified time limit, and the three tasks were assigned in a different order for each team within an experimental group based on a partial randomization. For the brainstorming task, teams were asked to generate as many ideas as they could for features that could be included in a better bathtub. Each member first generated his or her ideas separately and then the ideas were pooled. In the second task, the team members co-edited a section of a technical paper which contained nine errors. The team was to find and correct as many of the errors as they could. The third task was a negotiating task in which team members decided the fate of a machine operator who was caught smoking, despite the existence of a "no smoking" rule that was well known by all the employees of the firm.

Three independent variables were studied: file versus application sharing, limited video versus no video, and task type, which was a nested independent variable within all five groups. The dependent variables were: speed of performance, quality of task outcome and subjective user satisfaction.

The main objective of this study was to identify which CSCW tools are useful and usable for completing particular design-related tasks. This objective was pursued by considering the five hypotheses of this work:

- Tasks that involve negotiation or persuasion will be performed more effectively with video than without it;
- Users will be more satisfied when video is present;
- Tasks that involve reviewing and modifying documents will be performed more effectively with application sharing than with file sharing;
- Tasks that involve negotiation or persuasion will be performed more effectively in a face-to-face team than in a non-video CSCW team;

- Tasks that involve reviewing and modifying documents will be performed more effectively in a face-to-face team than in a CSCW team with the use of file sharing.

Support for the research hypotheses was limited. The performance measures yielded three statistically significant results. First, there was lower variability in the number of ideas generated by members within a team for the brainstorming task in groups utilizing video with application sharing than in groups using video with file sharing. Second, face-to-face teams generated more ideas, more unique ideas, and less variability in the number of ideas during the brainstorming task than groups using video with application sharing. This result leads to the conclusion that video with application sharing was more a hindrance than a help. Finally, face-to-face teams corrected a higher percentage of errors in the co-editing task than did the video with file sharing group. With respect to the measures of subjective user satisfaction, face-to-face groups were more satisfied overall than the other groups. Furthermore, users of video with file sharing were more satisfied with their effectiveness in completing the tasks than were users of video with application sharing. Finally, teams with access to file sharing were more satisfied than teams with application sharing with their efficiency in completing the tasks. This provides additional evidence that application sharing was not beneficial.

From these results, several trends were noted. These trends include:

- Face-to-face teams were more satisfied than groupware supported teams;
- Groupware-supported teams with video did not perform any better than teams without video, although teams with video were more satisfied with their effectiveness;
- Application sharing appeared to be more of a burden than a benefit;
- Teams adapted to the quality and capabilities of the tools provided;
- There was substantial variability in performance across teams within the same experimental condition.

The results reveal some of the benefits and shortcomings of current groupware tools for these types of tasks. Audio appeared to be an essential tool for these teams. The teams depended on it for communication. However, the limited video provided to some teams did not improve performance. Application sharing appeared to be a hindrance to the users. The application sharing tool was difficult to use; typically a single team member would control the application, while the other members provided input. Despite the current limitations of groupware, CSCW did enable teams to effectively perform the tasks tested; overall performance of the groupware-supported teams was comparable to that of the face-to-face teams. It is recommended that geographically distributed student design teams be provided an audio channel and file sharing capability to enable effective collaboration.

Bi-Objective Optimization of an Automotive Heat Exchanger Using Computational Fluid Dynamics
Anna Garrison, MS. Mechanical Engineering, May 1999

The goal of this research is to develop a methodology to optimize an automotive heat exchanger using computational fluid dynamics (CFD) coupled with an automated search algorithm. The general methodology is applicable to similar design problems such as electronic cooling. Except in some aerospace applications, CFD has not commonly been coupled with a systematic optimization process. This research bridges this gap and lays the foundation for more intensive future work.

Design of an automotive heat exchanger is bi-objective since the amount of heat transferred is maximized subject to different pressure drop constraints. These coupled, opposing design goals are achieved by determining the optimal geometric arrangement of the heat exchanger. CFD is used because it is able to model flow details that are responsible for improved designs. It has traditionally been reserved for "high tech" applications because it can be difficult to use and is computationally expensive. Recent developments in computer hardware and software have improved this situation, but some problems still exist. This research identifies some of these problems as they relate to heat exchanger optimization.

The flow and heat transfer within a two-dimensional "cell" model of an automotive heat exchanger is simulated using a commercially available CFD software package. The cell is a repeating unit of the heat exchanger, to which periodic boundaries are assigned. Two-dimensionality and the use of periodic boundaries reduce the computational load so that flow results are obtained relatively quickly. The flow is assumed to be steady and fully turbulent. Pressure drop across the cell and fin surface heat transfer are exported to the optimizer and, based on these results, the optimizer calculates new values for the design variables and the model geometry is updated.

CFD simulations predicted the effects of changing the model geometry on the heat transfer and pressure drop. Using the results, the optimizer maximized the heat transfer for four different pressure drop limits over a range of 1500 to 2500Pa. The four optimal design points were plotted and fit with a curve that approximates the maximum achievable amount of heat transfer for any specified value of pressure drop within the 1500 to 2500Pa range. This curve represents the Pareto set of the problem, and designers can select designs on the curve when trading off heat transfer and pressure drop.

Configuration Design Optimization Method (CDOM)
Pierre Grignon, Ph.D., Mechanical Engineering. May 1999

During the product design process, the optimization of the parameters (dimensions, shapes, materials) has been, until recently, the exclusive domain of the part design stage. This optimization is now spreading into two directions: first, to the conceptual design stage during which approximated mathematical models are solved to find the global parameters driving the design; second to the sub-assembly and assembly design stage during which the components are united to form the final product. It is only at this stage that system level characteristics, strongly linked to the desire of the customers, can be checked. These characteristics, considered as objectives by the engineer, and reflecting different knowledge fields, link parameters at various levels of the system and thus break the well established hierarchical organization of the full system. At present, no satisfactory solution is implemented to optimize these additional relations that transform the assembly design from a constraint satisfaction problem into a non-linear constrained multi objective optimization problem.

Hence, this work presents a method for optimizing system level assembly characteristics of complex mechanical assemblies by placement of freeform components. This method finds multiple solutions to the Configuration Design Problem and proposes a simple cooperation scheme with the engineer.

The review of the industrial applications showed that no assumptions could be made on the type of components and systems. However, system optimization usually occurred after component shapes and their functional links were settled. From the mathematical representation point of view, the variables can then be restricted to displacements and can be considered as continuous in all cases.

Once this is assumed, three areas are necessary to address the goal:

- define the complexity of an Engineering Configuration Design Problem (ECDP),
- define the method
- measure its performance.

In order to address the first goal, a mathematical formulation is adopted, that, unlike many formulations found in the literature review, could address any type of components (involving non-convex, hollow, sharp edges components). This formulation relies on the use of continuous variables for defining the authorized movements of the components with respect to each other and on penalty functions for penalizing unfeasible configurations. Then, based on the notion of function landscape, four criteria are chosen to answer the first need i.e. evaluating the complexity of the ECDPs. Trend, Roughness, Dilution of the feasible area and Dilution of the solution were defined for any type of C^1 functions and linked to simple characteristics of the ECDPs (size and number of the components, size of the system).

The second goal, the definition of the method, is addressed as finding multiple global extrema of a non-linear optimization problem. A Genetic Algorithm working on population of sets instead of population of individual points is proposed to search the variables space and to provide multiple solutions for three reasons. First, the GA works on several designs at the same time; second, it is able to deal with highly non-linear functions; and third it capitalizes on the knowledge acquired at previous trials. The analysis of the complexity classification of some well-known packing problems provided clues for proposing three enhancements to this initial method. First, the penalty should always be combined with the objective function for unfeasible configurations evaluation, then, the use of a Local Search, and Relative Placement contribute to decrease the CDP's complexity. Eventually, to increase the chances of escaping local minima, an adaptive range strategy was suggested.

Before verifying the validity of these choices, some criteria had to be designed to measure the quality of the Pareto set obtained using the CDOM. Three criteria are chosen to measure the quality of the set itself (distance from the extreme planes, distribution of the points, flatness) and two for measuring the performance of the CDOM (speed and repeatability). A series of cubes CDPs and two engineering cases were submitted to the method for validating the enhancements and the complexity classification. The conclusion of this part of the study pointed out that the Local Search and Range Adaptation enhancements were the most effective. Relative placement did not bring a clear advantage over the base strategy when dealing with CDPs in which the relative motion is not linked to a functional need.

Among the two types of criteria proposed for first rating the CDPs complexity and second for rating the CDOM, only the former were clearly satisfactory and can be reused in further studies. To assess the quality of a Pareto set, several criteria should be rethought. The CDOM successfully produces multiple solutions to the test cases submitted. Its drop in performance is linear while the CDPs complexity increases exponentially. It also proved to be able to handle any type of components. The lack of assumptions made on the type of objective functions makes it robust for handling continuous and discrete objectives. Working with displacements on one hand and, on the other hand, having the possibility to choose which components can move and which remain static, helps the engineer to keep a close contact with the optimization process. The limitations of the method concern the low number of moving components that can be taken into account at the same time (less than 10 system components using relative placement).

Appendices

Industrial Feedback

Comments on Clemson Discussion Topics from Paul Cole, Lockheed Georgia

Curriculum

Virtually all of our projects are now built around multi-disciplinary teams. New employees who have experience in the technical and psychological aspects of team efforts will certainly be more valuable to us as efficient team members. We are pleased to see that the proposed curriculum includes both aspects, which strongly influence the success of a team. Communication and the willingness to compromise are both enhanced by understanding of all technical aspects of a problem and proposed solutions. Equally important, and often overlooked, group dynamics have an important impact on team efforts. Knowledge of the inherent problems and teaming techniques are important skills for any engineer to have in today's design environment.

Systems Engineering plays a vital role in our current design efforts, and I would like to recommend that a systems engineering class be added to the curriculum, if it is not already there. All I have are the class titles, so I am not sure of the scope of the Systems Modeling and System Design courses.

Research Issues

Team work / Dynamics

I feel that this is a very vital research area, which can improve our application of Integrated Product Teams. We have implemented IPTs on most projects, and while they are an improvement over the earlier functional organizations, there are still improvements that can be made. We are not set up to research team dynamics issues and look forward to following and learning from your efforts. Hopefully we will be able to hold discussions with you on the problems we have seen in teams and can work with you to identify and implement improvements.

Groupware

Many (if not most) of our teams cannot be fully collocated. Groupware offers a solution to improved communications within and among teams. We have been working on implementing some of the commercial solutions, with minimal success to date. I am strongly interested in seeing research, which quantifies the benefits of groupware and helps identify where it is best applied, where its limitations are, and how it can be improved. We will be increasing our use of these tools and can collaborate with you on needs and solutions.

Human Centered Design

This is another very important area for research. I know of a long list of computer tools which were developed but never achieved their expected impact on the design process (why this is, and what to do about it is a personal soapbox of mine). My group, Design Technology, is chartered with developing tools for the design process, and we are very aware of the potential pitfalls. We are anxious to continue discussions with you in this area and to apply the results of your research in a production environment.

Automated Measurement/Processing Capability

This area does not seem to have a strong impact on our Advanced Design activities. Andy Bennett may have a different perspective in his comments.

Coupled Heat Transfer, Fluids, Electronic Packaging

This appears to be one of the best areas for our identification of an MDO project. Andy Bennett has talked to others in the subsystems packaging area and I believe that he has a reasonably scoped project to discuss.

Coordination Through Optimization

We strongly support your efforts in this area and would like to become more involved. We have applied optimization in several areas in the past, but are not applying anything like large scale MDO currently. We recognize the potential benefits, but are also familiar with the technical and cultural roadblocks to implementation. But, we are interested and do have a small effort underway which can provide a good point for coordination with you. This coordination can include all forms of cooperation on non- linear optimization methods, problem decomp, and related MDO issues.

Packing Using Genetic Algorithms

I have discovered that we have a (partially) automated method for computing deck spotting factor for aircraft on a carrier deck. This might still be a good problem to test/extend your algorithm, and we are always locking for a better solution to these problems. Aircraft "stuffing" is a manual, very labor intensive problem, and might present a good long term goal for your research in this area.

Aero-Manufacturing - Rapid Prototyping

We, and the other Lockheed aircraft companies, are strongly into rapid prototyping technologies (particularly SLA) for use in a range of design and manufacturing areas. We should continue discussions in this area to identify areas of mutual benefit.

Visualization

This is another hot topic in which we are very interested. Your visualization of 5-D data is an intriguing first step. We need to extend our discussions to see how the technique might be applied to some of our real world, every day problems. In the area of virtual reality, I am interested in applying several levels of capability (stereo terminals, headsets, immersion) to a typical task and quantifying the benefits in improved performance of a typical design task.

Example Problems

As I mentioned, Andy Bennett has the best definition of a multidisciplinary problem, which can be used for your classwork and methods development. In general his proposal involves the coupled design, packaging, cooling problem for aircraft avionics equipment. We will need to work through Andy to develop the project description that you need.

From our discussions to date I feel that we can also work together on several other projects including:

Quantification of groupware benefits
Application of human centered design approaches
Aircraft stuffing automation
Multi-variable data visualization - both for general data visualization and understanding MDO results

I will call you in couple of days to discuss the best way to continue the refinement of these ideas, whether it is by phone, face to face, or maybe using one of the collaborative tools.

Paul Cole
pcole@lasc.lockheed.com

Response from Steve Lancaster, Martin Marietta

We have had some group discussions and generated some comments relative to the questions you presented.

Curriculum:

It seems that the certificate focuses on an exposure to more courses which is good as far as it goes. Cross training between the areas of ME and IE is certainly a good idea. We are especially supportive of the Psych courses on teamwork.

Organizational dynamics should be taught as well as group dynamics.

Since we do not know the basic requirements for an engineering degree at Clemson we want to be sure to mention the need for some general Systems Engineering training. This should include such fields as

- Configuration Management
- Information Modelling
- Systems Decomposition and Relationships
- Traceability
- Metrics.

A general survey of the engineering disciplines should also be included.

Students should be made familiar with methods such as QFD and Taguchi as well as concepts such as Continuous Process (Product) Improvement.

We do not know what `ExSt' department stands for but we do believe that statistical engineering is important.

We are also interested in means of improving the English, technical writing and interpersonal skills of graduates when they hit the reality of industry.

Research topics:

The items most directly applicable are (in the order you presented them to me)

- team work / dynamics
- Groupware (collaborative hypermedia among them)
- Human centered design (assume this is Human Factors?)
- Auto. meas. processing capability
- Genetic Algorithms
- Rapid Prototyping.

The other items should follow these in areas of importance. We are insure what the tools or techniques you mentioned about decomposition are. (CI, Demaid, ...) Also, what does 'coordination through optimization' specifically mean?

Relative to the development of an improved non linear optimization package - this is very important. What would be nice would be a means to work this one abstract level higher. We work on this, Sirinivas is working on this, etc ....

Virtual reality is probably several years away from being practical for the everyday engineer. It would seem that the technology needs to mature somewhat but the big problem is cost. If the cost can be reduced significantly, then it becomes more useful for certain applications.

In terms of general visualization techniques the problem becomes the training of the engineer in how to interpret the two-dimensional projection of an n-dimensional object. We sense potential in this field but are unsure how it will apply specifically or how easy / hard it will be to use.

Problems to be supplied:

We need to postpone this section till after Xmas vacation. A key person from whom we wish to procure a problem is not back until then.

Thank you for the note. It is clearly time to explain the manner in which we are using KMS at MMC.

We are creating what we have called a "Process Management Environment" which we are using as the focal point for all of the work we do. The capability of KMS that is most important to us is the ability to spawn and grab results from any UNIX based tool.

We are focusing our efforts in three fields:

1) The capture, automation and reuse of engineering processes
2) Developing the "integrated environment" in which we do this
3) The acquisition and development of new GN&C technologies.

To these ends, interfaces with analytical tools in UNIX (matlab, fortran, easy5, matrixx, `C', etc.) are of paramount importance. We have i/f'd with matlab, fortran, and `C' fairly well. (We use file import and export a lot.)

We are currently exploring ways to i/f with an in-house created database tool called SEDB (Systems Engineering DataBase.) It is written using the Oracle RDBMS and is SQL compliant. This is the database which the company plans to use for the electronic capture of all of the systems requirements information on major projects. We have recently installed the sql tcp/ip software on our system and are starting to play with the SEDB i/f capabilities using SQL.

Another requirements tool we are seeking to create an i/f with is RDD-100. Actually, this has already been done at GE Corporate Research Center by a person named Emmett Black. His IR&D group is the original developer of CADRE Teamwork. He has developed an i/f with RDD-100 using KMS which we are hoping to test at some time in the future. Emmett's problem is that his funding has disappeared and he is fighting to restart it. Our problem is that no one in our group has used RDD-100 so that we have a long way to go to get anywhere.

We have created a variety of `tools' in KMS to allow us various ways of keeping track of various engineering notes. They are, to name a few, Electronic Engineering Notebook, Auto Process Tool, Schedule Tool, ...

There is a lot more to tell you but perhaps this is enough for now.

The people at KMS (a very small company) have been most cooperative with us and many of the changes they have implemented in their version 11 (of which we have a beta copy) have been at our request. At first, KMS seemed like a very cheesy little tool and it was not until we took advantage of the ways it interfaces with UNIX that we began to realize what we could accomplish with it. Rob Akscyn, the president of the company, is very involved in the hypertext community.

We have been at this since mid 1991.

Steve

G. Stephan Lancaster
Martin Marietta Astronautics
steve@archimedes.den.mmc.com

College of Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

Box 340921
Clemson, SC 29634-0921
gfadel@eng.clemson.edu
(803) 656-5620, fax -4435

January 11, 1995

Dear

We want to tell you about an exciting academic opportunity. This is an opportunity to get unparalleled experience---and to get paid for it at the same time.

The National Aeronautics and Space Administration (NASA) has awarded Clemson an unusual grant. Rather than being a grant to develop a product or to do specific research, NASA is asking Clemson to develop a very special curriculum. The grant resides in six departments: computer science, electrical engineering, industrial engineering, mathematical sciences, mechanical engineering, and psychology. This curriculum is aimed at developing students' abilities to work in interdisciplinary teams and exposing them to multidisciplinary design methods. Teamwork is the name of the game in business today. While it may seem trivial to work in a group---as engineers we assume we might work in a group---it is very hard to form a team from people with very divergent backgrounds. The Clemson group is working directly with several aerospace companies to be sure we are introducing the student to the types of problems and organizations used in industry.

As an inducement to students to join the program, we are offering grants-in-aid. These grants-in-aid will be awarded to those students who agree to take certain courses and work on particular projects. We would expect, for example, that engineers in one discipline would also take certain courses from another engineering discipline as well as computer science, mathematics, and psychology courses. We will be offering these grants-in-aid only to very exceptional students and for up to three years.

You are one of our outstanding first year students. We would like you to consider this opportunity before you preregister for your fall classes. We urge you to contact one of us directly so that we can talk about how you might fit the program in your regular curriculum. You can also get more information about the program under the web, at the following url: http://www.clemson.edu/~oheim/nasa_hp.html.

Please give it your serious consideration.

Sincerely,

Georges M. Fadel, Assistant Professor of Mechanical Engineering, Riggs 317B, 656-5620
Richard Figliola, Professor of Mechanical Engineering, Riggs 313, 656-5626
Mike Bridgwood, Associate Professor of Electrical and Computer Engineering, Riggs 224, 656-5934
Joel Greenstein, Associate Professor of Industrial Engineering, Freeman 104C, 656-5649

MDA Group

NASA Multidisciplinary Design and Analysis Program

Box 340921
Clemson, SC 29634-0921
gfadel@eng.clemson.edu
(803) 656-5620, fax -4435

March 28, 1995

To: Prospective Student

Re: Application for MDA Program

Thank you for your interest in the Multidisciplinary Design and Analysis Program. Enclosed with this letter is the application to the program that you are asked to fill if you have not done so through The web. Please return the form to one of the participating faculty and provide us with a write up describing why you are interested in the program. We will notify you of our decision before the end of the Registration period.

In order to provide you with more details about the program, we would like to invite you to an informal meeting on Tuesday April 4, at 5:00 pm in Brackett 120. Pizza and drinks will be available. We plan to tell you about course requirements, projects, and other opportunities such as industrial internships. Once we determine the number of students involved in the program, we will be able to tell you about the amount of the grant-in-aid, and its duration.

We are glad you showed interest in this program. We believe it will give you an advantage over your fellow students since you will be better prepared to respond to industry's needs.

See you Tuesday Evening,

Sincerely,

Mike Bridgwood (ECE)
George Fadel (ME)
Richard Figliola (ME)
Joel Greenstein (IE)
Mike Kostreva (MathSc)
Ron Nowaczyk (Psych)
D. Steve Stevenson (CpSc)

MDA Group

NASA Multidisciplinary Design and Analysis Fellowship

Box 340921
Clemson, SC 29634-0921
gfadel@eng.clemson.edu
(803) 656-5620, fax -4435

April 18, 1995

Dear

We are pleased to welcome you to the NASA Multidisciplinary Design and Analysis Fellowship Program. As mentioned in our presentation to you, we expect you to consult with one of the NASA MDA faculty members to tailor your program of study and sign up for certain classes outside your major (refer to handout on acceptable courses). Please see the advisor as soon as possible even though you will not be required to take any MDA related course until the Spring of 1996. At that time, you will be required to register for Psychology 457, Principles of Teamwork, which you may wish to use as one of your social sciences or elective courses. During your junior year, you will be expected to take one course each semester in another major, and similarly, in your senior year, you will also take one course each semester in another major. Should your major require a senior design project, we will attempt to coordinate a multidisciplinary project supplied by our industrial partners with your department.

Furthermore, you will be asked to maintain a 3.0 overall GPA in your courses, and a 3.0 GPA in the MDA courses. These courses outside your major will satisfy the requirements only if you earn a C or better. We will have periodic meetings with the graduate students to discuss research issues. You are invited to these meetings. We are also trying to set up internships with our industrial partners, we will let you know when more definite information is available.

In recognition of your participation, we are offering you a Grant-In-Aid in the amount of \$375.00 per semester (\$750 per year) for the 1995-96 academic year. This Grant-in-Aid may be renewed on an annual basis subject to satisfactory progress in your coursework and MDA requirements, and to the availability of funds. On satisfactory completion of the MDA requirements, and successful completion of your degree requirements, you will be awarded an MDA certificate from NASA.

Again, welcome and congratulations, we know you will benefit from being one of the few privileged participants in the program.

Sincerely,

Georges M. Fadel

I accept/decline the offer of the Grant-in-aid described above, and agree to the terms and conditions set forth.

____________________________ ____________________________

Signature Date

CIRCULAR

Collaborative
Interdisciplinary
Research at
Clemson
University -
Linking
Academia and the
Real-world

Partners:

Group Description and Purpose

The Clemson MDA Group is funded through a grant from NASA with support from Lockheed Martin. The project is funded to encourage multi-disciplinary work among engineering disciplines and supporting disciplines including computer science, mathematical science, and psychology. The group is charged with integrating undergraduate and graduate curricula of the participating diciplines to promote an interdisciplinary work environment. The group also supports undergraduate fellowships, and conducts research in MDA techniques. These include:

- Integration of electrical and mechanical interactions in avionic assemblies.
- Use of computers in MDA activities.
- CAD/CAM systems research.
- Computer supported collaborative work (CSCW) systems for engineering design use.
- Data Management
- Teamwork

Clemson Departments Presently Involved

- Computer Science
- Electrical and Computer Engineering
- Industrial Engineering
- Mathematical Sciences
- Mechanical Engineering
- Psychology
- **Clemson Faculty Involved**

Mike Bridgwood	mb@eng.clemson.edu	Electrical and Computer Engineering
Georges Fadel	gfadel@eng.clemson.edu	Mechanical Engineering
Richard Figliola	fgliola@clemson.clemson.edu	Mechanical Engineering
Joel Greenstein	joel.greenstein@eng.clemson.edu	Industrial Engineering
Mike Kostreva	flstga@clemson.clemson.edu	Mathematical Sciences
Ron Nowaczyk	nowaczykr@ecu.edu	Psychology (Currently at East Carolina University)
Steve Stevenson	steve@cs.clemson.edu	Computer Science

THE MULTIDISCIPLINARY DESIGN CERTIFICATE

Would you love to work on aerospace designs or on complex multidisciplinary designs, but do not necessarily want an aerospace degree?

Clemson University offers a unique program sponsored by NASA and major aeronautical companies which is offered across many disciplines.

THE MULTIDISCIPLINARY DESIGN CERTIFICATE

is offered to selected students who are interested in being prepared to work within a complex design environment. These students, whether interested in engineering, computer science, math, and behavioral sciences, have the opportunity to take courses from other departments, get familiar with the jargon of people they will work with, participate in industry supplied real senior design problems in multidisciplinary teams.

The certificate will be initially offered to students either interested or currently enrolled in the following disciplines:

Discipline	Contact
Computer Science	Dr. Stevenson
Electrical and Computer Eng	Dr. Bridgwood
Industrial Engineering	Dr. Greenstein
Mathematical Sciences	Dr. Kostreva
Mechanical Engineering	Drs Fadel, Figliola
Psychology	Dr. Nowaczyk

Depending on the requirements of the individual departments and colleges, students are asked to take free or technical electives from a selected set of courses, or possibly, take additional courses to complete a coherent program in multidisciplinary design and analysis. The students will also enroll in their senior year in a section of their existing design project, but will work on a multidisciplinary problem supplied by our industry partners.

Application for Admission into the MDA Program

- Online Application
- Ascii Application

Links to other MDA programs and related Topics

- Clemson's Research in Engineering Design and Optimization CREDO Lab
- Clemson University CSCW Group
- Virginia Polytechnic Institute -- MAD Center For Advanced Vehicles

Other Data Visualization Links

- Computational Engineering International

MDA Application

I. PERSONAL INFORMATION

____
Name

____
Mailing Address

____
City State Zipcode

____
Telephone Social Security Number

Date of Birth: ______________ Sex: ______________ Marital Status: ______________

Date you wish to enter program: ______________

Country of Citizenship: ______________

Previous Education:

	University	Degree	Major	GPA/Basis	Date Degree Expected/Received
1.					
2.					
3.					

SAT Scores: Verbal: ______________ Math: ______________

GRE Scores: Verbal: ______________ Quantitative: ______________ Analytical: ______________

Present Position: ______________

. ESSAY

Please attach an essay which indicates why you are interested in Multidisciplinary Design and Analysis and why you have chosen to apply. Include in the essay any relevant experience you have had and indicate any particular interests or research areas in multidisciplinary analysis, design and optimization that you are interested in. This essay should not exceed one thousand words. (Please mail essay to gfadel@eng.clemson.edu)

I. REFERENCES

1. ____
2. ____
3. ____

MDA CURRICULUM (Spring 1997)

The following table lists currently approved courses that can be taken to satisfy the MDA curriculum requirements at the undergraduate level. Students are expected to take the teamwork course, 3 courses outside their own discipline, and a senior design project that consists of an interdisciplinary design problem supplied by our industrial partners.
The table has to be read by column, according to the discipline of the student, XXXX means a student has to take the course as part of the curriculum, and XX means the course is optional and can count towards the requirements. Blank cells mean that either the course is required as part of regular curricula, or the student from a particular discipline cannot take that course for the MDA curriculum because of prerequisites or other conditions

Courses	ME	IE	ECE	CpSc	Science	Other
Psych 457 Principles of Teamwork	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
CpSc 210 Progrmng Methodology	XX	XX	XX		XX	XX
CpSc 211 Intro Comp Sci lang JAVA	XX	XX	XX		XX	XX
CpSc 340 Algthms and Data Str	XX	XX	XX		XX	XX
CpSc 455 Intro Comp Sci	XX	XX	XX		XX	XX
CpSc 481 Visualization	XX	XX	XX		XX	XX
Egr 412 Intr. Comp. Graphics	XX	XX	XX	XX	XX	XX
MthSc 206 Calc. of Sev. Vars				XXXX	XX	
MthSc 208 Intro to Diff Eq				XXXX	XX	
MthSc 311 Linear Algebra	XX	XX	XX			XX
MthSc 400 Probabilities		XX				
MthSc 440 Linear Programming	XX		XX			XX
MthSc 460 Numerical Analysis				XX	XX	
ExSt 411 Statistical Design			XX		XX	
ECE 201 Logic and Computing Devices						XX
ECE 272 Computer Organization						XX
ECE 308 Electronics & Electromechanics		XX				
ECE 407 Reliability	XX	XX				
ECE 409 Controls	XX					
ECE 432 Instrumentation	XX	XX	XX	XX	XX	XX
ECE 429 Organization of computers	XX	XX	XX	XX	XX	XX
IE 201 Systems Design I			XX	XX	XX	XX
IE 361 Ind. Quality Control			XX	XX	XX	XX
IE 380 Methods of OR I			XX	XX	XX	XX
IE 381 Methods of OR II			XX	XX	XX	XX
IE 384 Engineering Economy	XX		XX			

IE 452 Reliability Engineering	XX		XX			
IE 460 Quality Improvement Methods	XX		XX	XX	XX	XX
IE 461 Quality Engineering	XX		XX	XX	XX	XX
IE 482 Systems Modeling	XX		XX	XX	XX	
IE 488 Human Factors	XX		XX	XX	XX	XX
EM 202 Dynamics		XX	XX	XX	XX	
EM 322 Fluids		XX	XX	XX	XX	
ME 205 Numerical Methods		XX	XX	XX	XX	XX
ME 310 Thermo, HT for non ME			XX	XX	XX	XX
ME 423 Aerodynamics			XX			
ME 418 Finite Elements	XX	XX	XX	XX	XX	
ME 455 Design for CAM		XX	XX	XX	XX	XX
ME 471 Computer Aided Design		XX	XX	XX	XX	XX
Multidisciplinary Design	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX

P.O. Box 2406
Clemson, SC 29632
Krobers@Clemson.edu or
Keith.Roberson@ps.ge.com

October 18, 1998

Dr. Georges Fadel
Associate Professor
Dept. of Mechanical Engineering
202 Fluor Daniel Bldg.
Clemson, SC 29634

Subject: Assessment of Clemson's NASA MDA Program

Dr. Fadel:

I would like to preface this letter by conveying my gratitude for the opportunity to participate in the NASA MDA program since January 1996. It has allowed me to broaden my academic horizons while at the same time improving my personal and professional interaction skills. These have been very beneficial in making myself more marketable to employers and more productive in countless activities.

I joined the program in Fall of 1995 and begin the introductory course, Psychology of Teamwork, the following Spring semester. This course was extremely interesting and educational due to the relatively small group of MDA students and the excellent teaching ability of Dr. Ron Nowaczyk. The fundamental principles of teamwork have benefited me not only in school related projects, but also in industry, as I have worked and currently work with teams of diverse individuals, personally and professionally, and participate in numerous meetings. This exposure to teamwork building skills was immediately beneficial as the semester I was taking it, I was also interviewing for a Co-op position. Virtually every interview I had focused, or at least touched on, this new program designed to enhance the communication and interaction skills of engineers. All the companies felt this was an excellent idea to foster multidisciplinary education and it displayed my motivation to improve my academic diversity. Of the seven companies I interviewed with that made offers to ME's, I received six offers, allowing me to find my ideal position, which was very educational and instrumental in acquiring my current job. I feel my participation with the MDA program played an important role in attaining that Co-op position. I will never forget being interviewed by the plant manager of Mettler-Toledo, the company I co-oped for, and him asking me for advice about structuring meetings and forming task forces.

The material I have learned through my other MDA courses have also served me well. The engineering economics course opened my eyes to the real motivating factors behind the industry decisions. The college algebra course I took, which I assumed might be easy, was challenging and exposed me to new mathematical applications (such as proofs) and taught me improved ways of calculating and analyzing data. I was also able to take Aerodynamics, an ME course I would have otherwise missed since my technical electives were dedicated to undergraduate research. This course was very informative and interesting, and it helped me during interviews last spring for an internship which eventually led me to my position at GE Power Systems, where I currently work 30 hours a week and will continue working after graduation. My final MDA course was my senior design project in which three of the members were MDA participants and the fourth had also taken the psychology of teamwork course. Our meetings were extremely productive and we were able to incorporate different approaches to the project based upon our backgrounds.

The NASA program has uniquely benefited me in two additional ways. I received NASA Space Grant Consortium Scholarships for the 96-97 and 97-98 school years, which were tremendously helpful, as I have financed my college education. I can only assume that the NASA MDA program played some role in me attaining these awards, even ignoring the fact that the two are sponsored by the same organization. That was the only non-university scholarship I have ever received, though applying to many, due in part to my status as an out-of-state, middle class, white male with grades just under excellent. The second way the MDA program helped me was last year when I was deciding upon a summer internship; I very much wanted to work for NASA doing research for aeronautical vehicles. Dr Fadel and Dr Nowaczyk were helpful in laying out the procedure for applying and put me in contact with the appropriate people. Although I did not apply for the NASA internship, in favor of gaining more experience in industry, I was very pleased with and appreciative of the assistance I received from the MDA staff

Not only is this program appealing because of its academic benefits, but it is also a relatively easy program to participate in. If done properly, the required class each semester can go towards a free elective, humanity or technical elective, so it does not necessarily increase one's course load. It does, however, encourage a student to use their free elective or other credit hours wisely and to make the most of them. Most of the MDA courses I took ended up as free electives beyond what was required, only because I have been taking pre-law courses as free electives. However, the benefits of the additional education outweighed the extra work I had to do. The $375 stipend was helpful, but it was more of an afterthought than a motivating factor to participate.

I do have some constructive criticism for the program if it were to be extended. All the faculty members should play a more active role in the program through increased publicity, possible lectures, or even industry trips where multidisciplinary tactics are utilized. The program should also be more structured as to how it keeps students informed about activities, other participating members, and possible multidisciplinary projects.

I will be very disappointed if this project is discontinued over lack of funding based upon its realized outcomes versus the relatively low cost to maintain. If funding is not provided, the program should still be continued without a stipend for interested students, because students such as I would still participate solely for the advantages it provides. Only the top students of each major are invited to join, which I agree with, and this alone is a privilege to work and create contacts with other bright minds outside your major.

I have greatly enjoyed the MDA program and am fortunate that I was present during its active status. I feel very strongly that it should be continued at Clemson to improve the education of its students and to promote its status as a leading educational institution. Looking back upon my academic career here at Clemson, the NASA MDA program was the best academic activity I could have participated in and has had profound positive effects upon my education and career.

Sincerely,

Keith Roberson

1st year presentation

Clemson University
Multidisciplinary Design and
Analysis Program
December 1995

1

NASA MDA Undergraduate
Certificate Curriculum

2

Goals:

- Identify Roadblocks to Multidisciplinary Designs
- Propose Methods to Overcome Roadblocks
- Prepare Students for Multidisciplinary Work Environment

3

Curriculum Objectives

- Develop Multidisciplinary Task Awareness
- Develop Team Skills
- Multidisciplinary Design Experience

Involves Engineering, Mathematics, Computer Science, Psychology

4

Requirements

- 15 Semester Credit Hours (Approved List)
  - 3 Cr. Principles of Teamwork Course (Psychology)
  - 9 Cr. Engineering / Computer / Math Sciences (Outside Major Area)
  - 3 Cr. MDA Design Experience

5

Tangible Benefits

- Grant-in-Aid to Participants
- Optional Internship
- NASA Certificate

6

Projected Enrollment: Undergraduate

- **Targets Freshman/Sophomores for Three-Four Year Experience**

Year	Certificate	Non-Certificate
1995-96	10	6
1996-97	25	8
1997-98	40	8

7

Methods to Develop MDA Awareness in Undergraduates

- **Example Projects**
  - Aerodynamic Computational Flow Visualization
  - Materials Stress Visualization

10

NASA MDA Undergraduate Certificate Curriculum

- **Definition: Levels of Understanding**
  - 1 Introductory Subject Material; Casual Understanding
  - 2 Problem Solving Capability
  - 3 Open-Ended Design Capability

8

Course on Teamwork Principles & Processes

- **Undergraduate & Graduate Psychology Course**
- **First Course in the Certificate Program**
- **Offered for the 1St Time This January**
- **Considerable Emphasis on Assessment of Course**

11

NASA MDA Undergraduate Certificate Curriculum

Major Discipline Goal: Reach Level 3

Capstone Design Course

Cross Discipline Goal: Reach Level 2

Multidiscipline Design Teams Will Consist of Level 2 and 3 Mix

9

Teamwork Course Objectives

- **Familiarize Students With Teamwork Theory**
- **Emphasize Member Roles for Team Functioning**
- **Examine Constraints on Team Functioning**
- **Provide Students With Firsthand Team Experience**
- **Prepare the Students for Subsequent Courses in the Program**

12

Course Topics

- Theories of Group & Team Behavior
- Variables Influencing Team Functioning
- Organizational and External Influences on Teamwork
- Evaluation of Case Studies From Harvard Business Review and Administrative Science Quarterly
- Cooperative Learning and Team Dynamics in the Classroom

13

Student Mix

- Undergraduate and Graduate Students
- Variety of Disciplines (Engineering, Sciences, Psychology, Management)
- Spring 1995 Course:
  - 6 Engineering (4 Undergrads /2 Grad)
  - 5 Science (6 Undergrads)
  - 6 Psych/Mgmt (4 Undergrads / 2 Grad)

14

Visualizing Multidimensional Flow Fields

- Goal: Develop Interactive Software
- Intent: Develop Multidisciplinary Team to Meet Goal

15

Visualizing Multidimensional Flow Fields

- Method:
  - Team Engineers With Computer Scientists
  - Develop Analysis and Code
  - Visualize
    - » Conventional Methods
    - » Link to Virtual Environment
    - » Pedagogical Assessment

16

ECE Undergraduate Practicum

Department of Electrical & Computer Engineering
Department of Mechanical Engineering

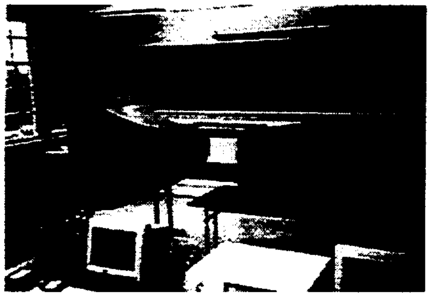
17

Goal of the Practicum

- Development of a Laboratory Class Which Incorporates Computer, Electrical and Thermal Engineering

18

Wind Tunnel



19

Disciplines Involved

- **Electronics**
- **Electromagnetics**
- **Heat Transfer**
- **Optimization**

20

Typical Project

- **Determine Package minimum CG Spacing**
- **Constraints:**
  - **Transfer Capacitance < 1.5pF**
  - **Mutual Inductance < 1.0 mH**
  - **Thermal Transfer < 0.06° C/Watt**
  - **Airflow at 30° C < 2 m/s**

21

Project Status

- **Hardware**
- **Courses**

22

Graduate MDA Program at Clemson

23

General Concepts

- **Graduate Program Not As Rigidly Specified As Undergraduate Program.**
- **Students to Take at Least One Interdisciplinary Course, Preferably Outside the Student'S Department.**
- **Student to Do at Least One Interdisciplinary Project. For Some This May Be Their Thesis.**

24

Academic Departments

- Computer Science.
  - Graphics, Software Engineering, AI, Communications
- Electrical and Computer Engineering.
  - Vlsi Reliability, Several Controls Courses, Information Theory, Simulation, Robotics

25

Academic Departments

- Industrial Engineering.
  - Human-Computer Topics, Quality Issues, Discrete Simulation
- Mathematical Sciences.
  - Several Optimization Courses, Matrix Analysis, Numerical Analysis, Seminars

26

Academic Departments

- Mechanical Engineering.
  - Finite Elements, Fluids, Heat Transfer, Design, Seminars
- Psychology.
  - Human Factors, Teamwork, Perception, Organizational Development, Group Dynamics, Seminars

27

Student Participation in Program

- Each Professor Has at Least One Student.
- Students Work in Interdisciplinary Teams.
- Students Are Encouraged to Take MDO Classes
- Students Have Projects Such As the CS-IE-Psych Collaborative Group.

28

Fellows and Supported Students

- Melroy D'Souza (IE)
  - Optimizing Product Development Through CSCW.
- Pierre Grignon (ME)
  - Working on Packaging Problems Using Genetic Algorithms
- Oliver Heim (CS)
  - Virtual Reality, WWW Support, CSCW.

29

Fellows and Supported Students

- Yusheng Li (ME)
  - Mixed Discrete Continuous Optimization.
- Stephane Morvan (ME)
  - VR Environment to Correct STL Files Before Rapid Prototyping.
- Mike Palazzo (Psych)
  - CSCW-Groupware Project and Teaming Roles.

30

Fellows and Supported Students

- **Robbie Tipton (ME)**
  - Optimization of Electronics Packaging.
- **Venugopal Challa (MS-ME)**
  - Developed an Algorithm to Perform Sequential Decomposition for Complex Problems.
- **Xibin Chen: (Phd-Mathsci)**
  - Computational Testing of Optimization Computer Codes: GRG2 and NRMFD

31

Fellows and Supported Students

- **Jacek Korycki (PhD-Math Sci)**
  - Theory, Algorithms and Applications of Norm-Relaxed Method of Feasible Directions.
- **Sayeejee Tatineni (MS-ME)**
  - Developed an Algorithm to Couple Optimizations Through Automatic Move Limit Evaluation.

32

Student Participation in Program: General Population

- **May or May Not Be Officially "MDA"**
- **May Take Any Courses Without Commitment.**
- **Encouraged to Think Multidisciplinary.**

33

NASA Multidisciplinary Design and Analysis Fellowship

Clemson University
Research Component

34

Outline

- **Objective**
- **Students Involved**
- **Human Centered Design**
- **Teaming**
- **Decomposition**
- **Optimization**
- **Coupling**
- **Ga Packing**
- **Multi-Dimensional Visualization**
- **Virtual Reality**
- **External Collaboration**

35

Objective

Develop Methodologies and Tools to Facilitate Design and Analysis of Multidisciplinary Problems.

36

A Methodology for
Decomposition in Design

37

Objective

- Understand the Process of Decomposition in Design
- Find Efficient and Logical Ways to Simplify Complex Systems
- Better Understand Complex Problems by Solving Simpler Subproblems

38

Decomposition Methodologies

- Object
- Aspect
- Sequential

39

Sequential Decomposition

- Activities Are Ordered in Some Sequence
- Communication Flow Between Design Teams Is Reduced Through Minimization of Feedback

40

Decomposition Methods

- Rank Order Cluster Algorithm
- Direct Cluster Algorithm
- Ci Algorithm and Branch and Bound Method
- Demaid
- Modified Triangularization

41

Decomposition Methods

- First Three Methods Deal With Identification and Resolution of Bottlenecks
- Demaid and the Modified Triangularization Deal With Scheduling and Reduction of Feedback Loops

42

Modified Triangularization

- 1. Identification of Order of Activities
- 2. Identification of Cycles
- 3. Ordering

43

Decomposition

- Implemented in Matlab
- Compared Favorably to Demaid

44

Norm Relaxed Feasible
Direction Algorithm

45

Optimization Problem

- Convex Constraint Set
- Minimization of Convex Function
- Smooth Inequality Constraints

46

Approach

- Use a New Direction Finding Subproblem Which Features
  - Quadratic Objective Function Used to Normalize Direction Vector
  - Linear Constraints
  - Only First Order Partial Deriv.
  - Solution by Robust Qp Solver

47

Comparison

PROBLEMS	DOT	CONMIN
10 BAR	better	worse
2-D 25 BAR	better	comparable
3-D 25 BAR	worse	worse
52 BAR	comparable	worse
200 BAR	worse	worse

48

Coupling Through Move-Limits

49

Objective

- Define Strategy for Coupling Disciplines That Requires Minimum Coordination Yet Reaches Common Optimum.
- Avoid Computation of Global Sensitivities
- Use Information Gathered When Building Approximations

50

Methodology

- Start at Feasible Point, Establish Move Limits and Carry Independent Optimizations
- Select Lowest Feasible Objective As Start for Next Optimizations
- Generate Move Limits for Each Discipline

51

Methodology

- Optimize Problems Independently
- Iterate Until Convergence. Restart With Smaller Moves Is Aff Solutions Unfeasible.
- Move Limits Calculated From 2 Pt Exponential Approximation

52

Looking at N-Dimensional Objects

- Why Would We Want to Do This?
  - It'S Fun to Contemplate; But
  - It May Help Understand Higher Dimensional Optimization and Dynamics.

53

State of the Program

- We Have One Viewer That Is Ray-Tracing Based.
- We Have One View That Is Projective Geometry Based:
  - The Four Axes Are Portrayed but Distorted.

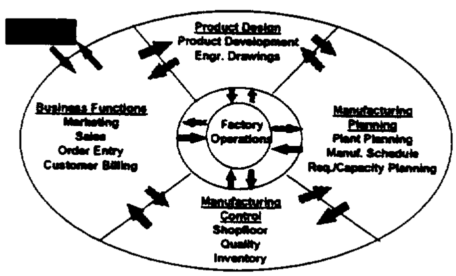
54

Optimizing the Product Development Process Through the Use of Electronic Media to Support Internal Collaboration

Department of Industrial Engineering
Department of Psychology

55

Typical Information Flow Cycle in an Organization



56

Internal Collaboration: Why It Is Needed

- Products Deigned Without Knowledge of Process Capabilities and Tolerances
- Problems Pertaining to Product Characteristics May Not Be Documented
- Redundancy in New Product/Component Design

57

Internal Collaboration: Why It Is Needed

- Absenteeism at Product Development Team Meetings
- Lack of Suggestions From Non-Team Members
- A Deeper Understanding of the Phenomenon of Groupwork Itself Is Required

58

Objectives

- Develop a Computer-Supported Collaborative Work (CSCW) System in a Real World Organization That Will Meet the Growing Needs of a Shared Information Retrieval and Communication System Between Design, Manufacturing and Other Related Areas
- Increase Our Knowledge and Understanding of Contextual Issues Encountered in Such a Collaborative System

59

Approach and Methodology: Milestones Achieved

- Field Research at Two Product Development Organizations
- Use a Combination of:
  - Gould'S Design for Usability --Human-Centered Design Approach
  - Ethnography
  - Contextual Design

60

Approach and Methodology: Milestones Achieved

- Ongoing Work-in-Progress
  - Conduct Needs Analysis
  - Develop Paper-and-Pencil Prototypes
    - » Testing and Evaluation
  - Iterative Design

61

Where Do I Go From Here?

- Develop Different Software Segments of the System
  - Evaluate and Iterate Using Pre-Designed Scenarios and Usability Specification Tables
- Final Integration
  - Integrate All the Segments of the System and Evaluate the System Through a Certain Time Period

62

Where Do I Go From Here?

- Evaluation
  - Time Series Analysis
  - Multivariate Analysis
  - Univariate Analysis Using Quasi-Controlled Experimental Scenarios

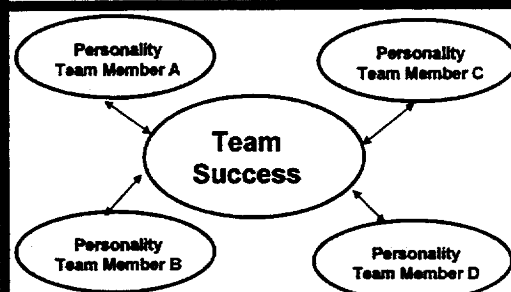
63

Teamwork & Personality Characteristics

Departments of Psychology, Computer Science, Electrical Engineering, Industrial Engineering, & Mechanical Engineering

64

Purpose of Study



65

Methodology

- Subjects: 125 Undergrads & Grads in Engineering and Science Courses
- Students Completed a Personality Inventory
- Measures:
  - Objective: Team Products
  - Subjective: Instructor Ratings (Grades) & Student Ratings of Team Members

66

Personality Characteristics

- Conscientiousness
  - Goal-Oriented
  - Well-Organized
- Openness
  - Receptive to New Ideas
  - Broad Interests & Perspectives
  - Imaginative

67

Role Functions

- Ability to Resolve Conflict
- Encourage New Ideas
- Attentive to Team Processes
- Sensitive to Other Team Members
- Participative
- Leadership

68

Current Status

- Completing Data Collection
- Planning a Paper for Submission to the Multidisciplinary Analysis and Optimization Symposium Next September.

69

Computer-Supported Groupware Platform

- Design Team of Faculty and Graduate Students From Computer Science, Industrial Engineering & Psychology
- Develop a Software Platform for Student (and Industry Mentor) Use for Sharing of Information on Team Projects.
- Possible Platforms: WWW, Lotus Notes.

70

2nd year presentation

Clemson University Multidisciplinary Design and Analysis Fellowship Program 1996

Faculty

Mike Bridgwood	ECE
Wei Chen	ME
Georges Fadel	ME
Richard Figliola	ME
Joel Greenstein	IE
Mike Kostreva	Math
Ron Nowaczyk	Psych
Steve Stevenson	CpSc

2

Undergraduate Students (7/96)

David Brown
John Clayton
Lance Flood
Jen Ford
Tracy Commerson
Rebecca Hartman
Heather Gerberich
Trent Kirk
Keith Roberson
Michael White

3

Graduate Students (7/96)

Nathan Adams	ME
Jill Kirschman	IE
Gary Loughry	ECE
Courtland McLay	CpSc
Todd McKee	ME
Chad Patton	Psych
William Stinson	CpSc
Robert Tipton	ME
Amy Ward	Math

4

Undergraduate MDA Curriculum at Clemson University

Curriculum Objectives

- Develop Multidisciplinary Task Awareness
- Develop Team Skills
- Multidisciplinary Design Experience

Involves Engineering, Mathematics, Computer Science, Psychology

6

Requirements

- 15 Semester Credit Hours (Approved List)
  - 3 Cr. Principles of Teamwork Course (Psychology)
  - 9 Cr. Engineering / Computer / Math Sciences (Outside Major Area)
  - 3 Cr. MDA Design Experience

7

Tangible Benefits

- Grant-in-Aid to Participants
- Optional Internship
- NASA Certificate

8

Summary

- Flexible Curriculum That Provide Breadth
- No Net Addition of Course Requirements - Technical and Free Electives Are Used
- Problem-Solving Capability Is Goal for Courses Outside Major
- Cornerstones: Teaming Issues and Multidisciplinary Capstone Projects

9

Graduate Program

- No Specific Course Requirements
  - Teaming Course
  - Advanced Design
  - Engineering Optimization
  - Uncertainty & Robustness in Design
  - Computer Visualization
  - Global Optimization
  - Aerodynamics
  - CAD

10

Principles & Processes of Teamwork

Ron Nowaczyk

Course Information

- Initial course in certificate program
- Taught at undergraduate/graduate level
- Fulfills social science elective
- Emphasis on theory, research, and applications

12

Course Objectives

- Familiarization with teamwork principles
- Highlight theories of team dynamics
- Review research on effective teamwork
- Provide practical experience working with teams

13

Course Structure

- Enrollment limited to 20 students.
- Students from different disciplines (engineering, science, business, psychology).
- Students assigned to teams of 4 to 5 students each.
- Class project included.
- At least 2 team exercises per week as part of class.

14

Course Outline

- Theories of team dynamics
- Internal factors that influence team performance
- External (organizational) factors that influence team performance
- Technology and teamwork
- Case studies of effective teamwork

15

Student Evaluation

- Course rated above University average in terms of student development, teacher capability, and course structure.
- Exercises and class project viewed as very worthwhile.
- Heterogeneity of teams was a positive.
- Grading of team performance and individual contributions needs improvement.

16

Future Issues

- Improved monitoring and grading of team assignments.
- Refinement of class exercises.
- More case studies.
- Continued use of class project.
- Teamwork website: http://chip.eng.clemson.edu/htdocs/psych499/

17

Personality and Team Performance

Ron Nowaczyk
Richard Perlow
Michael Palazzo

Purpose

- Examine relationship between personality and team performance
  - *Openness:* one's receptiveness to, or tolerance of, new ideas, experiences and approaches.
  - *Conscientiousness:* an individual's degree of organization, persistence, and motivation in goal-directed behavior.

19

Methodology

- Undergraduate & Graduate Computer Science & Engineering students
  - completed a personality inventory
  - worked as part of design teams
  - evaluated team members as to their performance
    - » on the task assignment
    - » as a team member

20

Results for Individuals

- Openness -> 42% ranking
- Conscientiousness -> 61% ranking
- No significant relationships with *individual* ratings and personality traits.
- Conscientiousness & Openness were related (r = .37)

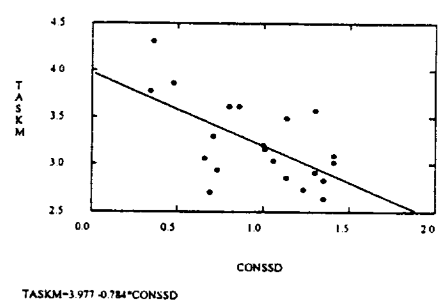
21

Results for Teams

- 21 Teams (N = 3 to 5)
- Variability in Conscientiousness Negatively Related to Task and Team Facilitation Ratings
- Openness Marginally Related to Team Facilitation and Variability in Task Ratings

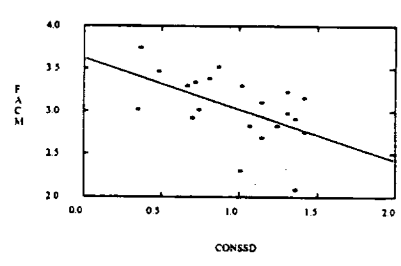
22

Relationship between σ for Conscientiousness & Task Performance



23

Relationship between σ for Conscientiousness & Team Facilitation



24

Conclusions

- Findings
  - Treat the team as the "unit" of study
  - Personality can play a role in "perceptions" of team performance
- Limitations
  - Students not engineers/scientists as subjects
  - Task assignment
  - Concept of "Team"
- Continuing Research
  - Examining "conscientiousness" in a controlled setting

25

Developing a Computer-Based Teamwork Platform

Joel Greenstein
Ron Nowaczyk
Steve Stevenson
Jill Kirschman
Chad Patton
Mickey Shah
John Underwood

Teamwork Platform: Problem

- Reviewed Current Literature
- Investigated Existing Groupware and Software Products
- Talked to Prospective Users
- Design a prototype for usability testing

27

Platform Requirements

- Basic Sketching
- Basic Text
- Document and Graphics Sharing
- Simple Group Calendar
- E-mail
- User Centered
- World Wide Web Based
- Platform Independent
- Inexpensive

28

Shortcomings of Current Products

- None Have All Desired Features
- Not Targeted at Engineering/Scientific Fields
- Not Truly Real Time
- Not All Are Web-Based
- Expensive
- Proprietary

29

Current Challenges

- Learning JAVA and Creating CGI Scripts
- Multiple Programming Languages/Applications Required
- Integration and Compatibility of All Languages and Applications
- Technological Constraints of Web
- Diversity of Operating Systems Being Used
- Variety of Product Requirements

30

Current Status

- Learning JAVA and CGI Scripting
- Created Simple Whiteboard
- Produced CSCW System Web Page
- Developing Other Features of System
- Ensuring Package is Easy to Use

31

Plan for the Future

- Complete Fully Functional User-Centered CSCW System
- Test System on Multidisciplinary Teams
  - Undergraduate
  - Graduate
  - Industry
- Incorporate Changes as Needed

32

Assessment of Cooling Technologies for Avionics Integration

R. Tipton & R.S. Figliola
Clemson University

A. Bennett & E. Hodge
Lockheed-Martin

Project Objectives

- Assess new technology for avionics cooling
- Assess aircraft-level impact (multi-system integration)
- Assess new methodologies to speed up design

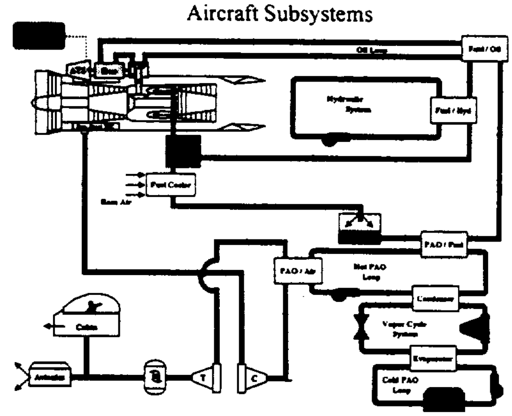
34

Problem Statement

- Integrate a spray cooled avionics chassis into the ECS of a fighter aircraft
- Evaluate the aircraft-level impacts of this new technology
- Optimize the overall system (minimize the total fuel penalties and GTW of the aircraft)

35

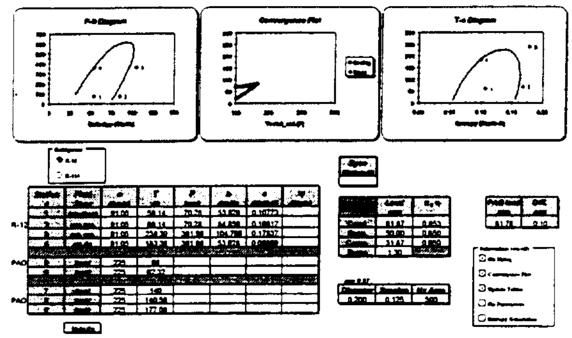
Aircraft Subsystems



Analysis Procedures

- Two analyses are performed to evaluate and optimize the ECS of the aircraft
  - a traditional first law detail analysis performed on a component-by-component basis
  - a second law exergy analysis performed to determine its validity in optimizing the overall system

37



Detail Analysis

- Goal
  - Evaluate ECS performance of aircraft using traditional thermodynamic first law techniques
- Methodology
  - Integrate seven major aircraft subsystems
  - Perform detailed thermodynamic analysis on all major components within each subsystem
- Outcome
  - Provide ram air flow / drag measurements, equipment weights, engine horsepower and bleed extraction
  - Determine total GTW and fuel penalties of aircraft

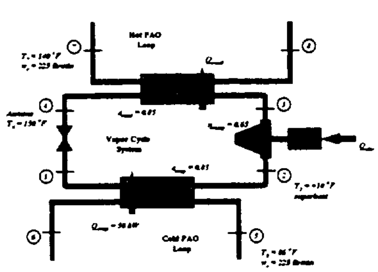
38

Energy Management Concept

- Goal
  - Incorporate energy managed approach to cut modeling time and facilitate the process of aircraft design
- Methodology
  - Evaluate each component of the system in terms of its entropy generation or flow exergy (available energy)
  - Sum the entropy generation of each component to determine the total entropy generation of the system
- Outcome
  - Define a direct correlation between entropy generation of individual component and the GTW or associated fuel penalty of the aircraft

41

Schematic of Vapor Cycle System With all Given Inputs



Status

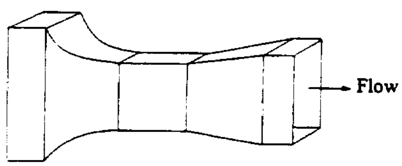
- Lockheed-Martin and Clemson have teamed to evaluate methodology
- Student intern has completed summer at Lockheed -Martin. Ongoing visits continue the relationship
- Initial study should be completed by late winter

42

A Low Velocity Wind Tunnel as a Vehicle for Multidisciplinary Studies in an Undergraduate Electrical Engineering Laboratory Sequence

M. Bridgwood
G. Loughry
D. Claussen
E. Psaier

Air Tunnel Project



- Measure & Control
  - Air throughput
  - Air temperature
  - Package position

44

Student Projects

- Gary Loughry
  - Airflow measurement and control
  - System integration
- D. Claussen
  - Parameter measurement
  - Optimization
- E. Psaier
  - 3-D package position control
  - Ultrasonic flowmeter

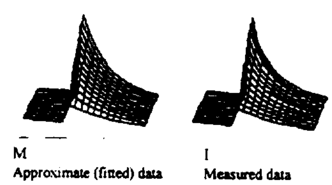
45

Laboratory Methodology

- Parameter measurement
- Empirical modeling
- Optimization

46

Mutual Inductance Data



$M_{x,y} := A_{x,y} \cdot \exp(-k_{x,y} \cdot y)$

$A_{x,y} := -0.612 \cdot x + \alpha$

$k_{x,y} := \beta \cdot (1 - a \cdot x - b \cdot x^2 - c \cdot x^3)$

47

Future Work

- More complex geometries
- Transducer design projects
- Reliability test modeling

48

Multi-Objective Packaging Optimization using a GA

Georges Fadel
Pierre Grignon
Todd McKee

Multiobjective Design

- Packaging problem
- CAD-GA interface
- 3D packing
- Objectives:
  - Center of gravity, vibrations
  - Heat transfer, volume minim.
  - Maintainability

50

Multiobjective Design

- Solved GA based 1D, 2D, 3D cog and volume minimization
- GA typically tries initially volume minimization, then order crossover based reproduction places center of gravity

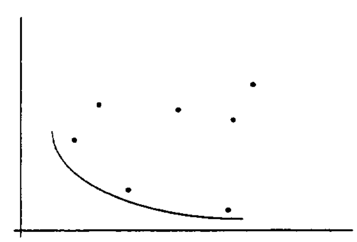
51

Multiobjective Design

- New method using Pareto definition instead of objectives drives family of solutions towards Pareto set.

52

Multiobjective Design



53

Multiobjective Design

- 3D multiobjective space
- CAD to GA link (non-convex)
- Visualization of n-Dim spaces
- Approximate models

54

Constrained Optimization
&
Systems Modeling & Optimization

Mike Kostreva
Amy Ward

Constrained Optimization

- Improvements and enhancements to Norm-Relaxed Method of Feasible Directions
  - Self-Tuning Variant
  - Specialized Constrained Line Search Control and Coordination

56

Constrained Optimization

- Numerical testing
  - Problem generator for large scale random convex programming problems
  - Rosen/Suzuki problems: Quadratic objective functions and constraints

57

Systems Modeling and Optimization

- Model of system which considers a general heat flow or fluid flow system in equilibrium

58

Systems Modeling and Optimization: Features

- Bounded two dimensional region
- Nonconstant coefficient of diffusion
- Mixed boundary conditions
- Finite element model

59

Systems Modeling and Optimization: Features

- Optimization (minimax) subject to
  - Lower bound on solution
  - Upper and lower bounds on boundary function
- Boundary function is acting as control variable
- Preliminary results obtained with MATLAB

60

Function Based Design

Georges Fadel
Charles Kirschman
Nathan Adams

Functional Design and Metrics

- Taxonomy for function based design
  - Motion
  - Control
  - Power/matter
  - Enclosure

62

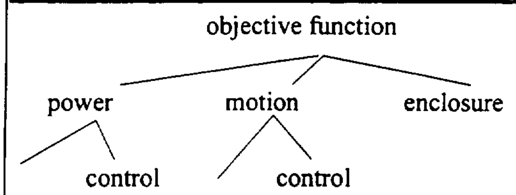
Function Based Design

[Create, Convert, Modify, Transmit, Dissipate] [Rotary, Linear, Oscillatory, Other] Motion to [Rotary, Linear, Oscillatory, Other]

[Continuous, Discrete] [User, Feedback] Control of [Power, Motion, Information]

63

Function Based Design



64

Function Based Design

- Tc/Tkl software implementation
- Needs more tests
- Tied to metrics

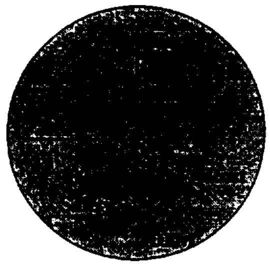
65

Design Metrics

	Perf.	DFM	Ergs	Safety	Icost
Perf.	↗	↓	0	↓	↓
DFM	↓	↗	↓	0	↑
Ergs	0	↓	↗	↓	↓
Safety	↓	0	↑	↗	↓

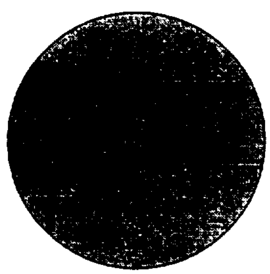
66

Design Metrics



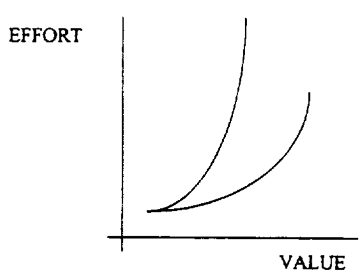
67

Design Metrics



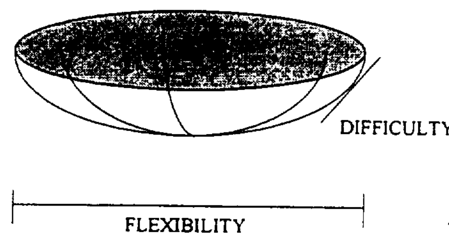
68

Design Metrics



69

Design Metrics



70

Design Metrics

- Software for system evaluation complete
- Comparing method to multiattribute utility
- Need test cases
- Difficulty in assessing increase in value and icost

71

Perceptual Issues in 4-D Visual Understanding

Steve Stevenson
Ron Nowaczyk
Chad Patton
John Underwood

4-D Visualization: Problem

- Projecting 4-D objects
  - based on 3-D graphics
  - that meet user perceptions
- Developing a 4-D viewer
  - graphics issue
- Testing human perception

73

4-D Viewer

- PHIGS standard extended to 4 - D
  - "short" one dimension
- Study restricted to orthographic and perspective projections
- User can:
  - scale
  - rotate
  - translate

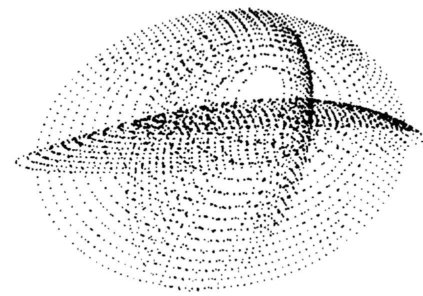
74

4-D Objects

- 7 objects used
  - regular figures
  - normalized
- Conics could not be produced using lines

75

4-D Elliptical hyperparaboloid



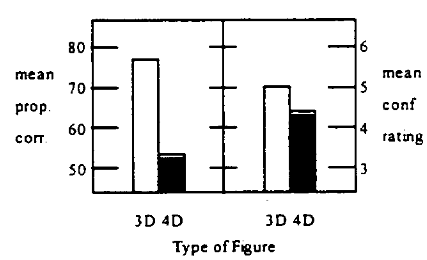
76

Perceptual Study

- 6 Engineering & Computer Science participants (Faculty & Graduate Students)
- 3-D & 4-D figures presented
- Identify figure
- Confidence in matrix representation & equation

77

Findings



78

Conclusions

- Performance with the current viewer suffers going from 3-D to 4-D
- Workable methodology for testing the viewer
- A "motion" metaphor is appropriate
- Rethinking of traditional projections and their perceptual interpretation
- Future goal is to expand beyond 4-D

79

Spin-offs: Government

- NASA - NOVA (Education Grant)
  - Development of science education courses
- NSF - Product Realization Consortium
  - Teaming principles in manufacturing education
- TACOM
  - Developing proposal

80

Spin-offs: Industry

- Duke Power
  - Susceptibility study of distributed multi-technology industrial control systems subject to impulsive EMI
- Ryobi Motor Products
  - Computer-Supported Collaboration in the Product Development Process

81

3rd year Presentation

NASA Multidisciplinary Design and Analysis Fellowship

Clemson University
May 1997
Programmatics & Education

1

Participants

- **Mechanical Engineering**
  - Georges Fadel - Jason Bokar
  - Richard Figliola - Wei Chen
- **Electrical and Computer Engineering**
  - Michael Bridgwood
- **Industrial Engineering**
  - Joel Greenstein

2

Participants

- **Computer Science**
  - Steve Stevenson
- **Mathematical Sciences**
  - Michael Kostreva
- **Psychology**
  - Ron Nowaczyk

3

Industry Partners

- **Lockheed Martin**
  - Lockheed Georgia
    - Advanced Design Group
  - Martin Marietta Astronautics
    - Advanced Integration Design
- **FORD**
- **PRATT & WHITNEY**

4

Students

- **25 Undergraduates (Engineering & Sciences)**
- **10 Graduates**
  - Engineering
  - Computer Science
  - Mathematics
  - Psychology

5

NASA MDA Undergraduate Certificate Curriculum

7

Undergraduate MDA Curriculum at Clemson University

Georges Fadel Richard Figliola
Michael Bridgwood Joel Greenstein
Steve Stevenson Michael Kostreva
Ron Nowaczyk

8

Curriculum Objectives

- Develop Multidisciplinary Task Awareness
- Develop Team Skills
- Multidisciplinary Design Experience

Involves Engineering, Mathematics, Computer Science, Psychology

9

Requirements

- 15 Semester Credit Hours (Approved List)
  - 3 Cr. Principles of Teamwork Course (Psychology)
  - 9 Cr. Engineering / Computer / Math Sciences (Outside Major Area)
  - 3 Cr. MDA Design Experience

10

Tangible Benefits

- Grant-in-Aid to Participants
- Optional Internship
- NASA Certificate

11

Projected Enrollment: Undergraduate

- Targets Freshman/Sophomores for Three-Four Year Experience

Year	Certificate	Non-Certificate
1995-96	10	6
1996-97	25	8
1997-98	40	8

12

NASA MDA Undergraduate Certificate Curriculum

- Definition: Levels of Understanding
  - 1 Introductory Subject Material; Casual Understanding
  - 2 Problem Solving Capability
  - 3 Open-Ended Design Capability

13

NASA MDA Undergraduate Certificate Curriculum

Major Discipline Goal: Reach Level 3

Capstone Design Course

Cross Discipline Goal: Reach Level 2

Multidiscipline Design Teams Will Consist of Level 2 and 3 Mix

14

Course on Teamwork Principles & Processes

- Undergraduate & Graduate Psychology Course
- First Course in the Certificate Program
- Offered for the 1St Time Spring 1996
- Considerable Emphasis on Assessment of Course

15

Teamwork Course Objectives

- Familiarize Students With Teamwork Theory
- Emphasize Member Roles for Team Functioning
- Examine Constraints on Team Functioning
- Provide Students With Firsthand Team Experience
- Prepare the Students for Subsequent Courses in the Program

16

Course Topics

- Theories of Group & Team Behavior
- Variables Influencing Team Functioning
- Organizational and External Influences on Teamwork
- Evaluation of Case Studies From Harvard Business Review and Administrative Science Quarterly
- Cooperative Learning and Team Dynamics in the Classroom

17

Student Mix

- Undergraduate and Graduate Students
- Variety of Disciplines (Engineering, Sciences, Psychology, Management)
- Spring 1996 Course:
  - 6 Engineering (4 Undergrads /2 Grad)
  - 5 Science (5 Undergrads)
  - 6 Psych/Mgmt (4 Undergrads / 2 Grad)

18

Methods to Develop MDA Awareness in Undergraduates

- Example Projects
  - Aerodynamic Computational Flow Visualization
  - Materials Stress Visualization

19

Visualizing Flow Fields

- Goal: Develop Real-Product-Interactive Software
- Intent: Develop Multidisciplinary Team to Meet Goal

20

Visualizing Flow Fields

- Method:
  - Team Engineers With Computer Scientists
  - Develop Analysis and Code
  - Visualize
    - » Conventional Methods
    - » Link to Virtual Environment
    - » Pedagogical Assessment

21

CONCLUSIONS

- Flexible Curriculum That Provide Breadth
- No Net Addition of Course Requirements - Technical and Free Electives Are Used
- Level 2 Understanding Is Goal for Courses Outside Major
- Cornerstones: Teaming Issues and Multidisciplinary Capstone Projects

22

DISCUSSION

- ROADBLOCKS
  - INSTITUTIONAL
    - » BUDGETARY
    - » RECRUITING
    - » INTER UNIVERSITY
  - INDUSTRY COLLABORATION
    - » PROBLEM TAYLORING
    - » TIME AND AVAILABILITY
    - » PRIORITY

23

ECE Undergraduate Practicum

- Department of Electrical & Computer Engineering
- Department of Mechanical Engineering

24

Current Objective

- Development of a Laboratory Class Which Incorporates Computer, Electrical and Thermal Engineering

25

Typical Project

- Determine Package minimum CG Spacing
- Constraints:
  - Transfer Capacitance < 1.5pF
  - Mutual Inductance < 1.0 mH
  - Thermal Transfer < 0.06° C/Watt
  - Airflow at 30° C < 2 m/s

28

Disciplines Involved

- Electronics
- Electromagnetics
- Heat Transfer
- Optimization

26

Project Status

- Hardware
- Courses

30

Graduate MDA Program at Clemson

32

General Concepts

- Graduate Program is Flexible.
- Students to Take at Least One Multidisciplinary Course, Preferably Outside the Student's Department.
- Students to Do at Least One Multidisciplinary Project. For Some This May Be Their Thesis.

33

Academic Departments

- Computer Science.
  - Graphics, Software Engineering, AI, Communications
- Electrical and Computer Engineering.
  - VLSI Reliability, Several Controls Courses, Information Theory, Simulation, Robotics

34

Academic Departments

- Industrial Engineering.
  - Human-Computer Topics, Quality Issues, Discrete Simulation
- Mathematical Sciences.
  - Several Optimization Courses, Matrix Analysis, Numerical Analysis, Seminars

35

Academic Departments

- Mechanical Engineering.
  - Finite Elements, Fluids, Heat Transfer, Design, Seminars
- Psychology.
  - Human Factors, Teamwork, Perception, Organizational Development, Group Dynamics, Seminars

36

Student Participation in Program

- Students Work in Multidisciplinary Teams.
- Students Are Encouraged to Take MDA Classes
- Students Have Projects Such As the CS-IE-Psych Collaborative Group.
- Students Work on a Topic that Enables MDO Work

37

Current Projects

- Optimizing Product Development Through CSCW. (IE, CS, Psych)
- CSCW-Groupware Project and Teaming Roles. (Psych, CS, IE)
- Virtual Reality, WWW Support, CSCW. (CS, ME, Psych)

38

Current Projects

- Development of CIDES (IE, CS, ME)
- Packaging Problems Using Genetic Algorithms (ME, Math, CS)
  - placement
  - routing
- Mixed Discrete Continuous Optimization. (ME, Math)

39

Current Projects

- Pareto optimization, identification of pareto space
- Constraint Management in MDO - Applied to Configuration Design
- Novel Rubber band optimization for Packing problems

40

Completed Projects

- VR Environment to Correct STL Files Before Rapid Prototyping. (ME, CS)
- Optimization of Electronics Packaging. (ME, ECE, Math)
- Algorithm to Perform Sequential Decomposition for Complex Problems. (ME, ECE, Math)

41

Completed Projects

- Theory, Algorithms and Applications of Norm-Relaxed Method of Feasible Directions. (Math, ME)
- Algorithm to Couple Optimizations Through Automatic Move Limit Evaluation. (ME, Math)

42

Student Participation in Program: General Population

- May or May Not Be Officially "MDA"
- May Take Any Courses Without Commitment.
- Encouraged to Think Multidisciplinary.

43

Outline

- Objective
- Human-Centered Design
- Teaming
- Decomposition
- Optimization
- Coupling
- GA Packing
- Multi-Dimensional Visualization
- Virtual Reality
- External Collaboration

46

Objective

Develop Methodologies and Tools to Facilitate Design and Analysis of Multidisciplinary Problems.

47

NASA Multidisciplinary Design and Analysis Fellowship

Clemson University
Research Topics

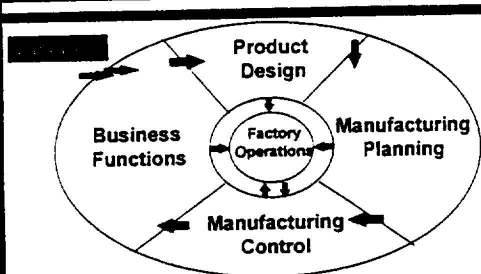
45

Optimizing the
Product Development Process
Through Computer-Supported
Internal Collaboration

Departments of Industrial Engineering,
Psychology, and Computer Science

49

Typical Information Flow Cycle in an Organization



50

Need for Internal Collaboration

- Products Are Designed Without Knowledge of Production Process Capabilities and Tolerances
- Producibility Problems Related to Product Characteristics Are Not Documented
- It Is Difficult for All Stakeholders to Provide Input

51

Objectives

- Develop a Computer-Supported Collaborative Work (CSCW) System in a Real World Organization That Will Meet the Needs of the Design and Manufacturing Functions
- Increase Understanding of Contextual Issues Encountered in Supporting Collaboration for Product Development

52

Work Accomplished

- Field Research at Two Product Development Organizations
  - AT&T GIS
  - Ryobi Motor Products
- Methodologies Employed
  - Human-Centered Design
  - Ethnography
  - Contextual Design

53

Work in Progress

- Needs Analysis
- Paper-and-Pencil Prototyping
  - Testing and Evaluation
- Iterative Design

54

Work to Follow

- Software Development
  - Develop, Test, and Refine CSCW Software to Meet Usability Specifications
- System Integration
  - Integrate Software Components
- System Evaluation
  - Quasi-Experimental Scenarios
  - Time-Series Analysis of Real-World Implementation

55

Potential Payoffs

- Increased Collaboration Between Design and Manufacturing
- Reduced Product Manufacturing Cost
- Development of Guidelines for Implementing Collaborative Systems That Support the Product Development Process

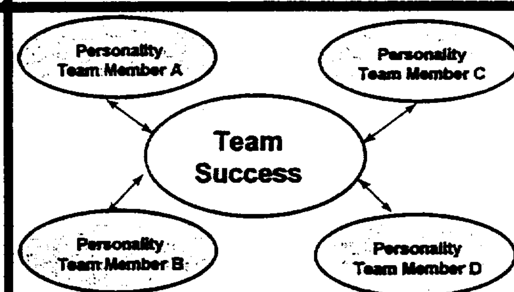
56

Teamwork & Personality Characteristics

Departments of Psychology, Computer Science, Electrical Engineering, Industrial Engineering, & Mechanical Engineering

58

Purpose of Study



59

Methodology

- Subjects: 125 Undergrads & Grads in Engineering and Science Courses
- Students Completed a Personality Inventory
- Measures:
  - Objective: Team Products
  - Subjective: Instructor Ratings (Grades) & Student Ratings of Team Members

60

Personality Characteristics

- Conscientiousness
  - Goal-Oriented
  - Well-Organized
- Openness
  - Receptive to New Ideas
  - Broad Interests & Perspectives
  - Imaginative

61

Role Functions

- Ability to Resolve Conflict
- Encourage New Ideas
- Attentive to Team Processes
- Sensitive to Other Team Members
- Participative
- Leadership

62

Current Status

- Completing Data Collection
- Planning a Paper for Submission to the Multidisciplinary Analysis and Optimization Symposium Next September.

63

A Methodology for Decomposition in Design

Departments of Mechanical Engineering
and Industrial Engineering

65

Objective

- Understand the Process of Decomposition in Design
- Find Efficient and Logical Ways to Simplify Complex Systems
- Better Understand Complex Problems by Solving Simpler Subproblems

66

Decomposition Methodologies

- Object
- Aspect
- Sequential

67

Sequential Decomposition

- Activities Are Ordered in Some Sequence
- Communication Flow Between Design Teams Is Reduced Through Minimization of Feedback

68

Decomposition Methods

- Rank Order Cluster Algorithm
- Direct Cluster Algorithm
- CI Algorithm and Branch and Bound Method
- DeMaid
- Modified Triangularization

69

Decomposition Methods

- First Three Methods Deal With Identification and Resolution of Bottlenecks
- DeMaid and the Modified Triangularization Deal With Scheduling and Reduction of Feedback Loops

70

Modified Triangularization

- 1. Identification of Order of Activities
- 2. Identification of Cycles
- 3. Ordering

71

Decomposition

- Implemented in Matlab
- Compared Favorably to DeMaid

72

Norm-Relaxed Feasible Direction Algorithm

Departments of Mathematical Sciences and Mechanical Engineering

74

Optimization Problem

- Convex Constraint Set
- Minimization of Convex Function
- Smooth Inequality Constraints

75

Approach

- Use a New Direction Finding Subproblem Which Features
  - Quadratic Objective Function Used to Normalize Direction Vector
  - Linear Constraints
  - Only First Order Partial Deriv.
  - Solution by Robust QP Solver

76

Performance of Norm-Relaxed Algorithm

PROBLEMS	DOT	CONMIN
10 BAR	worse	better
2-D 25 BAR	worse	comparable
3-D 25 BAR	better	better
52 BAR	comparable	better
200 BAR	better	better

77

Coupling Through Move-Limits

Departments of Mechanical Engineering and Mathematical Sciences

78

Objective

- Define Strategy for Coupling Disciplines That Requires Minimum Coordination Yet Reaches Common Optimum.
- Avoid Computation of Global Sensitivities
- Use Information Gathered When Building Approximations

79

Methodology

- Start at Feasible Point, Establish Move Limits and Carry Independent Optimizations
- Select Lowest Feasible Objective As Start for Next Optimizations
- Generate Move Limits for Each Discipline

80

Methodology

- Optimize Problems Independently
- Iterate Until Convergence. Restart With Smaller Moves If All Solutions Unfeasible.
- Move Limits Calculated From 2 Pt Exponential Approximation

81

Configuration Design

Departments of Mechanical Engineering,
Computer Science, and Mathematical Sciences

83

Configuration Design

- Overall Goal
  - Define a Method to Improve the Quality of Complex Mechanical Systems by Relocating Their Components.
- Specifics
  - Relocate Components but Preserve Their Connectivity.
  - Propose Sets of Optimal Locations Based on Approximated System Definition.
  - Propose Sets of Optimal Locations Based on Final Product Definition.

84

Computational Tools

- Shape &Topology Models (-> Constraints)
  - Simple Shapes, CAD Models.
  - Networks, Graphs, Grammars, Lists to Represent Topology.
- Analysis (States & Behaviors -> Objectives)
  - Differential Equations, Customized Analytic Functions, Heuristics
- Optimization
  - Deterministic, Non-Deterministic, Constrained

85

Research Orientation

- Formalization of Configuration Design
- Realistic Models
- Automated Evaluation Method
- Initial Evaluation of Method Effectiveness
- A Posteriori Evaluation of the Quality of the Approximate Solution
- Information Management Method
- Learning Strategies

88

Applications

- Volume Minimization
- Balance Maximization
- Surface & Length Minimization
- Temperature Optimization
- Accessibility Maximization
- Performance Maximization

86

Summary

- Features of Conventional Approaches
  - Few Simple Shapes
  - One Objective at a Time
  - Non-Expensive Objectives
- Difficulties
  - Combinatorial Explosion, NP Problems
  - Non-Convex, Disjoint Domains
  - Integer Variables
  - Discontinuous, Nonlinear Objectives
  - Representation of Realistic Situations

87

Adventures in Graphics

Departments of Computer Science,
Mechanical Engineering, and Psychology

90

Looking at N-Dimensional Objects

- Why Would We Want to Do This?
  - It's Fun to Contemplate; But
  - It May Help Understand Higher Dimensional Optimization and Dynamics.

91

State of the Program

- We Have One Viewer That Is Ray-Tracing Based.
- We Have One View That Is Projective Geometry Based:
  - The Four Axes Are Portrayed but Distorted.

92

External Collaborations

94

Industry

- Visits
- Exchange of Data
- Internships
- Funding

95

University Collaboration

- Visits
- Course Syllabi Exchange
- Exchange of Case Studies
- Exchange of Papers and Reports
- Common Seminars (Video Link)
- Exchange of Software
- Mosaic Sites

96

FUNCTION BASED DESIGN

98

MULTIOBJECTIVE DESIGN

- PACKAGING PROBLEM
- CAD-GA INTERFACE
- 3D PACKING
- OBJECTIVES:
  - CENTER OF GRAVITY, VIBRATIONS
  - HEAT TRANSFER, VOLUME MINIM.
  - MAINTAINABILITY

99

MULTIOBJECTIVE DESIGN

- SOLVED GA BASED 1D, 2D, 3D COG AND VOLUME MINIMIZATION
- GA TYPICALLY TRIES INITIALLY VOLUME MINIMIZATION, THEN ORDER CROSSOVER BASED REPRODUCTION PLACES CENTER OF GRAVITY

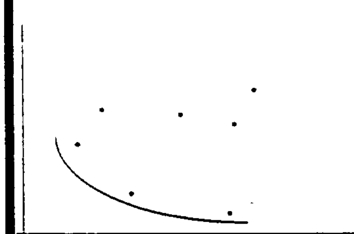
100

MULTIOBJECTIVE DESIGN

- NEW METHOD USING PARETO DEFINITION INSTEAD OF OBJECTIVES DRIVES FAMILY OF SOLUTIONS TOWARDS PARETO SET.

101

MULTIOBJECTIVE DESIGN



102

MULTIOBJECTIVE DESIGN

- 3D MULTIOBJECTIVE SPACE
- CAD TO GA LINK (NON-CONVEX)
- VISUALIZATION OF N-DIM SPACES
- APPROXIMATE MODELS

103

FUNCTIONAL DESIGN AND METRICS

- TAXONOMY FOR FUNCTION BASED DESIGN
  - MOTION
  - CONTROL
  - POWER/MATTER
  - ENCLOSURE

104

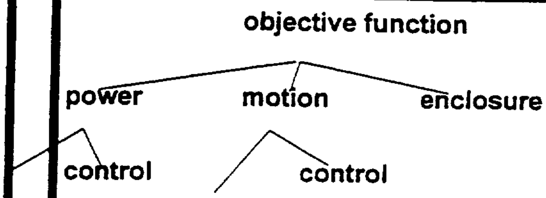
FUNCTION BASED DESIGN

create	rotary	MOTION	rotary
convert	linear		to linear
modify	oscillatory		oscillatory
transmit	other		other
dissipate			

continuous	user	CONTROL	power
discrete	feedback		of motion resulting information

105

FUNCTION BASED DESIGN



106

FUNCTION BASED DESIGN

- TC/TKL SOFTWARE IMPLEMENTATION
- NEEDS MORE TESTS
- TIED TO METRICS

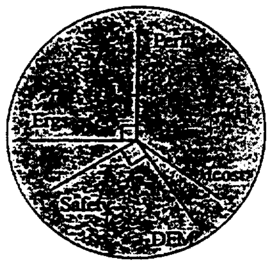
107

DESIGN METRICS

	Perf.	DFM	Ergs	Safety	Icost
Perf.	↗	↓	0	↓	↓
DFM	↓	↗	↓	0	↑
Ergs	0	↓	↗	↓	↓
Safety	↓	0	↑	↗	↓

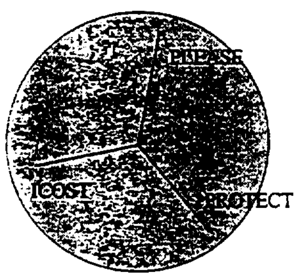
108

DESIGN METRICS



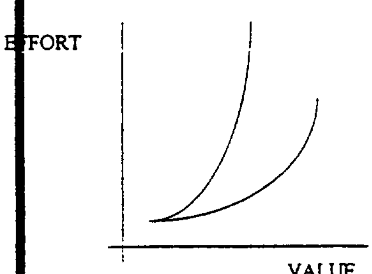
109

DESIGN METRICS



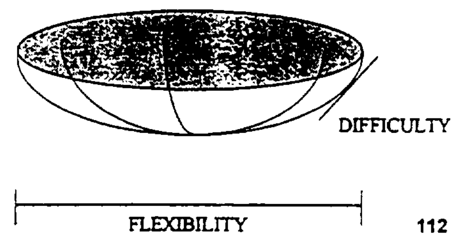
110

DESIGN METRICS



111

DESIGN METRICS



112

DESIGN METRICS

- SOFTWARE FOR SYSTEM EVALUATION COMPLETE
- COMPARING METHOD TO MULTIATTRIBUTE UTILITY
- NEED TEST CASES
- DIFFICULTY IN ASSESSING INCREASE IN VALUE AND ICOST

113

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1999	Final Contractor Report

4. TITLE AND SUBTITLE

The Component Packaging Problem—A Vehicle for the Development of Multidisciplinary Design and Analysis Methodologies

5. FUNDING NUMBERS

WU–505–90–52–00
NGT10008
NAG3–2046

6. AUTHOR(S)

Georges Fadel, Michael Bridgwood, Richard Figliola, Joel Greenstein, Michael Kostreva, Ronald Nowaczyk, and D. Steve Stevenson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Clemson University
Center for Advanced Manufacturing
Clemson, South Carolina 29634–0925

8. PERFORMING ORGANIZATION REPORT NUMBER

E–11722

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CR—1999-209159

11. SUPPLEMENTARY NOTES

These are in the grant award of May 8, 1997. The grant was awarded from Headquarters and Glenn was assigned to monitor it. It was transferred to Christos C. Chamis after Dr. L. Berke retired, at Headquarters' request. Project Manager, Christos C. Chamis, Research and Technology Directorate, NASA Glenn Research Center, organization code 5000, (216) 433–3252.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category: 39 Distribution: Nonstandard

This publication is available from the NASA Center for AeroSpace Information, (301) 621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report summarizes academic research which has resulted in an increased appreciation for multidisciplinary efforts among our students, colleagues and administrators. It has also generated a number of research ideas that emerged from the interaction between disciplines. Overall, 17 undergraduate students and 16 graduate students benefited directly from the NASA grant: an additional 11 graduate students were impacted and participated without financial support from NASA. The work resulted in 16 theses (with 7 to be completed in the near future), 67 papers or reports mostly published in 8 journals and/or presented at various conferences (a total of 83 papers, presentations and reports published based on NASA inspired or supported work). In addition, the faculty and students presented related work at many meetings, and continuing work has been proposed to NSF, the Army, Industry and other state and federal institutions to continue efforts in the direction of multidisciplinary and recently multi-objective design and analysis. The specific problem addressed is component packing which was solved as a multi-objective problem using iterative genetic algorithms and decomposition. Further testing and refinement of the methodology developed is presently under investigation. Teaming issues research and classes resulted in the publication of a web site, (http://design.eng.clemson.edu/psych499/) which provides pointers and techniques to interested parties. Specific advantages of using iterative genetic algorithms, hurdles faced and resolved, and institutional difficulties associated with multi-discipline teaming are described in some detail.

14. SUBJECT TERMS

Teaming; Genetic algorithms thermal; Stress; Geometry modeling; Educational curriculum

15. NUMBER OF PAGES

117

16. PRICE CODE

A06

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102